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COMMITTEE ON THE PEACEFUL USES
OF OUTER SPACE

REPORT ON THE UNITED NATIONS/FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS/EUROPEAN SPACE AGENCY WORKSHOP ON MICROWAVE REMOTE SENSING TECHNOLOGY ORGANIZED IN CO-OPERATION WITH THE GOVERNMENT OF BRAZIL

(São José dos Campos, Brazil, 19-23 November 1990)

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INTRODUCTION

A. Background and objective

1. At its thirty-seventh session, in its resolution 37/90 of 10 December 1982, the General Assembly endorsed the recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82) and decided that the United Nations Programme on Space Applications should promote the dissemination of information on advanced space applications and new systems developments among managers and decision makers, particularly for the benefit of the developing countries.

2. The United Nations/Food and Agriculture Organization of the United Nations/European Space Agency Workshop on Microwave Remote Sensing Technology was one of the activities of the Programme for 1990 that were endorsed by the General Assembly in its resolution 44/46 of 8 December 1989. The Workshop was co-sponsored by the Government of Brazil and hosted by the Instituto Nacional de Pesquisas Espaciais (INPE) at São José dos Campos, São Paulo, Brazil, from 19 to 23 November 1990 for the benefit of participants from the Economic Commission for Latin America and the Caribbean (ECLAC) region.

3. The objective of the Workshop was to expose the participants to various aspects of current and future microwave remote sensing systems, including the acquisition, processing, archiving and applications of the data generated by such systems. The presentations delivered at the Workshop provided an overview of microwave remote sensing, the physical principles of image formation and the interpretation and analysis of the elements involved in the applications of the technology to tropical forest environments, agriculture, hydrology and oceanography. The experiences and programmes of a number of countries, including those of some Latin American countries, in the use of microwave remote sensing, were also presented. The Workshop concluded with working group deliberations focusing on three major areas - data accessibility and availability, education and applications development.

4. The present report, which covers the background, objective, organization, observations and conclusions of the Workshop as well as a summary of the lectures presented, has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Sub-Committee. Participants will report to the appropriate authorities in their respective countries.

B. Organization and programme of the Workshop

5. The participants were professionals with several years of experience in remote sensing or in developing plans for the management of natural resources or in other programmes which can potentially benefit from the applications of microwave remote sensing. The Workshop was attended by 57 participants from the following Member States and organizations: Argentina, Bolivia, Brazil, Canada, Chile, Colombia, Ecuador, Jamaica, Paraguay, Peru, Suriname, United States of America, the Food and

Agriculture Organization of the United Nations (FAO), the European Space Agency (ESA), Intera Kenting (Canada) and the United Nations (Outer Space Affairs Division).

6. Funds allocated by the United Nations, FAO and ESA for the organization of the Workshop were used to defray the cost of international air travel and a daily subsistence allowance to cover hotel, board and incidental expenses of 19 participants. The Government of Brazil, through INPE, provided the conference facilities and local transportation for all participants.

7. Opening addresses were presented by Mr. Mucio Roberto Dias, Deputy Director, Instituto Nacional de Pesquisas Espaciais, on behalf of the Government of Brazil, by Mr. Jurg Lichtenegger, on behalf of the European Space Agency, and by Mr. Sergio Camacho, on behalf of the United Nations.

8. The programme of the Workshop (annex I to the present report) was developed by the United Nations, FAO and ESA in consultation with INPE. The Workshop was conducted through a number of plenary and working group sessions. At the latter, the participants discussed the issues associated with microwave remote sensing and made the observations that follow.

I. OBSERVATIONS OF THE WORKSHOP

9. The deliberations of the Workshop at the working group sessions focused on three major areas of microwave remote sensing - data accessibility and availability, education and applications development. The discussions included references to the experience acquired in satellite microwave remote sensing by the international scientific and user communities from experimental missions such as the SEASAT (1978) experimental oceanographic mission and the more recent SIR-A (1981) and SIR-B (1984) missions conducted by the National Aeronautics and Space Administration (NASA) of the United States of America (see para. 69 below). The Workshop noted that a significant amount of experience has been acquired within the ECLAC region on airborne microwave remote sensing through projects that have been conducted in countries such as Brazil, Colombia and Peru.

Data accessibility and availability

10. In addition to data to be obtained from airborne microwave sensor systems as part of specific projects in the region, beginning with the launching in 1991 of ERS-1 (ESA), there will be a continuous supply of satellite-obtained microwave data for at least the next 10 years. Other sources of such data will include the ALMAZ satellite to be launched by the Union of Soviet Socialist Republics in 1991, Japan's JERS-1 (1992) and Canada's RADARSAT (1994).

11. In order to benefit from the applications of microwave remote sensing data, particularly in areas where optical and infra-red data are either unobtainable or unsuitable, countries and institutions should explore various avenues for obtaining microwave data. As a first step, a list of contact points for sources of existing microwave data for the region should be prepared. Since the Latin American Society

of Remote Sensing Specialists (SELPER) serves the purpose, among other things, of disseminating information within the remote sensing community in the ECLAC region, such a list could be prepared by SELPER and subsequently distributed through its national representatives. Thereafter SELPER could also prepare a map of the region indicating the areas for which microwave data exists and the scales at which they are available. The establishment of an information system association within the region might follow these efforts.

12. Similarly, SELPER's journal could be used by the remote sensing community to discuss such issues as (a) the advantages, difficulties and possible drawbacks of establishing common data formats for the region as well as for the development of transportable software for microwave remote sensing applications; and (b) the needs, requirements and possible solutions that would have to be addressed by potential users of the technology.

13. The Workshop noted that data from any source could be used to develop image processing and applications analysis techniques. In this respect, prospective researchers and users should establish relationships with other institutions which have microwave data sets. The existence of a network of personal and institutional contacts among professionals working in the area of microwave remote sensing should facilitate such an effort. The list of participants at the Workshop would be a convenient starting-point.

Education

14. The Workshop emphasized that there was a need for more remote sensing education programmes to be established at universities in the ECLAC region. This need exists in spite of a number of ongoing programmes at some of the universities and space-related institutions in the region and of ad hoc training of professionals within specific projects. In this connection, the Workshop welcomed the proposal by the United Nations to establish a regional centre for space science and technology education that would initially focus on remote sensing. The Workshop indicated that such a Centre was necessary to assist participating teachers in preparing and teaching the needed programmes/courses.

15. Universities and space institutions that already have remote sensing education programmes should strengthen them by including in their curricula the theory and applications of microwave remote sensing. Appropriate co-operation relationships should be established between universities and institutions of higher education regarding long-term education courses. Such relationships would need the support of both university and government authorities.

16. In order to create a growth environment for remote sensing (for both teaching and research), it is necessary to convince the decision makers of the benefits to be derived from the technology. Such motivation could be provided through the application of remote sensing and satellite meteorology to the mitigation of the effects of natural disasters or to the solution of problems of national interest.

17. For individuals from user agencies who might work with microwave remote sensing in the near future, training in the technology should proceed in stages. Such a training programme should provide a solid background in visible and infra-red

remote sensing followed by workshops that provide an overview of the characteristics and applications potentials of microwave remote sensing. Subsequent stages of training should include hands-on training experience with microwave data from areas that are familiar to the participants; this would be supplemented with opportunities that would allow the participants to receive updated knowledge on the characteristics of the data, new processing and analysis techniques and new applications areas.

18. It is also necessary to organize specialized workshops in such areas as high-level mathematical methods and numerical analysis techniques as related to the processing and analysis of microwave data. Specifically, it is necessary to motivate and involve professionals in mathematics and in the development of software that could be used to solve such problems as removing speckle from a microwave image and to correct for some of the image degradation effects that accompany the acquisition of the data.

19. Since there are limited resources to organize workshops on a given subject, such workshops should address the issues which would most directly benefit the region. An effective way of ensuring this is for individuals and their institutions to suggest topics to be dealt with in future activities to be organized in the region by bodies of the United Nations System as well as other entities. On the basis of the needs manifested by the remote sensing community, workshop and courses that would benefit the entire region could also be organized by local institutions.

20. Advances in the processing and analysis of microwave data would result in a greater percentage of these processes being performed on computer systems, including personal-computer equipment. Thus, in order to promote the exchange of experiences, there should be constant communication among the remote sensing community regarding the compatibility of the software and hardware that are now available or will be developed for remote sensing analysis. An international committee, such as the Committee on Earth Observations Satellites (CEOS), should be requested to prepare a booklet identifying the compatibility of existing software packages and various hardware systems. Such an effort should define standards to ensure that the software and hardware to be developed is also compatible with those already in existence.

Development of applications

21. Through collaboration with local institutions, a number of airborne microwave remote sensing projects in the ECLAC region have been conducted by institutions from outside the region. Since Member States will continue to undertake projects of this type, it should be a requirement at the time that each project is being established that a training component be included so that the know-how is transferred to the local institution and its personnel at the conclusion of the project.

22. A wide range of projects calling for the application of microwave remote sensing have either been carried out or are being proposed in different parts of the ECLAC region. Specific ongoing or prospective projects in the region include

the use of microwave data to study the Pacific Coast area (Colombia) where the annual rainfall exceeds 8,000 mm; geology, tectonics, cartography, hydrology, oceanographic studies (Brazil, Chile and Peru); tropical forest studies (Brazil, Colombia, Ecuador and Peru); analysis of coastal wave frequencies (Mexico); delineation of political boundaries over snow/ice covered areas, archaeology (Chile); and surveying for bauxite deposits (Jamaica).

23. A co-operation project on the tropical forests in the Amazon region using microwave remote sensing could consolidate all the national plans in that subregion. SELPER has already identified objectives for several projects for the Amazon region using visible and infra-red data; the addition of microwave data to these projects should be considered since this would contribute to ongoing efforts.

24. In order for applications to be developed, it is essential that in addition to training opportunities microwave data be made available so that interpretation methods can be developed by the research community. In the initial stage, data from the RADAM project (Brazil) could be used for this purpose. The remote sensing community should also emphasize the importance of having early access to ERS-1 data in order to develop applications experience. To promote a wide use of these data, SELPER could publicize the names of ESA's Principal Investigators in the region and should request ESA to make such data available to more researchers, possibly through a Guest Investigator programme. In anticipation of RADARSAT's launching in 1994, ECLAC's remote sensing community should approach the Canada Centre for Remote Sensing to obtain simulated RADARSAT data, particularly that which might be collected over the region.

25. The workshop also suggested that SELPER could make an important contribution to the ongoing global debate in the sense that data for studying the environment within the framework of programmes such as Mission to Planet Earth (1992) and events such as the United Nations Conference on the Environment and Development (Brazil, 1992) should be made available free of charge to the research community.

II. SUMMARY OF PRESENTATIONS

A. Overview of microwave remote sensing

26. Remote sensing of the Earth, from both aircraft and satellite-borne sensors, has proved to be a useful tool for surveying, evaluating and monitoring natural resources, various land use features and the environment in general. Most of the experience that has been accumulated to date by the international research and applications communities has been in the use of data obtained in the visible and infra-red portions of the electromagnetic (EM) radiation spectrum. The observation of the Earth in this range of wavelengths (i.e., 0.4 to 14 micrometres) is based on measurements of either the reflected or the emitted radiation by objects on its surface. Thus sensors operating in the visible and infra-red range ultimately depend on the Sun as the source of energy.

27. Because of the absorption characteristics of the atmosphere, measurements of radiation in the visible and near infra-red range require clear-sky, daylight conditions. At the long end of the infra-red range, the radiation is due to the

temperature of the body being observed. Thus, the radiation observed from a cloud-covered area of the Earth is due mostly to the cloud temperature and not to the ground features. Consequently, for regions of the Earth with persistent cloud cover (e.g., tropical areas), the amount and timeliness of the information that can be remotely obtained in the visible and infra-red range of the EM spectrum are severely limited.

28. Microwave remote sensing provides the capability for day or night observations and under clear sky or cloudy conditions. This is possible because most microwave sensors provide their own source of radiation (i.e., independent of the Sun) and because microwave radiation, which is in the 1 mm to 1 m portion of the EM spectrum, can penetrate through clouds.

29. Microwave sensors can be divided into passive and active systems. Passive systems measure microwave radiation emitted by the ground features or emitted by the Sun and reflected by the surface. Active systems "illuminate" the area under observation and measure the strength and time delay of the radiation that is reflected by the ground features.

30. Microwave instruments used for remote sensing fall into one of the following four categories: (i) microwave radiometers used for emitted radiation measurements; (ii) radar scatterometers used to obtain point-type information such as sea-state; (iii) radar altimeters used as ranging instruments to measure altitudes above sea level and heights; and (iv) imaging radars that produce geographic information about the area being observed as well as characteristcs of the objects present in the image. Imaging radar instruments have found the greatest variety of applications. The geographic character of these images permits the user to superimpose (register) them on existing cartography or imagery obtained in the visible or infra-red portions of the EM spectrum.

31. The interaction of microwave radiation with objects on the surface of the Earth depends strongly upon the electrical properties of the objects and the surface roughness relative to the wavelength of the incident radiation. The electrical properties of matter are determined by its dielectric coefficient, which is highly sensitive to water content. An analysis of the returned signal can therefore provide information on the nature of the objects, their relative size, distribution and moisture content.

32. Radar images can be obtained from either an aircraft or a satellite. In both cases, the images are obtained by transmitting microwave pulses at an angle to the vertical and measuring the intensity and time delay of each returned pulse. The first return pulse corresponds to the object whose projected distance in the direction of the sensor system is the smallest. In general this pulse corresponds to the object closest to the flight path. Because of the geometry between the incident pulse and the height of objects, the projected distance in the direction of the sensor system of the upper part of an object is smaller than the distance of its corresponding ground-point projection. This effect is known as foreshortening and makes terrain of high relief appear in the image as falling towards the radar. On the images, foreshortening causes the slopes to become extended and to appear darker. This effect can be corrected with reference to a digital terrain map.

33. The foreshortening effect can become very severe so that the top of a mountain appears to be closer to the flight path than the foot of the mountain. This effect is called layover and cannot be corrected. Other image degradations include a speckle effect, which appears as noise on the image and is related to the frequency coherence of the system, as well as several effects due to the motion of an object with respect either to the sensor system or to other objects in the field of view of the radar.

34. Because the difference in distance between objects directly beneath an aircraft or a satellite is very small, the corresponding return signals cannot be electronically discriminated. For this reason airborne radars have been designed to scan objects at some distance to one of the sides of the aircraft and are called side-looking airborne radars (SLAR). The spatial resolution attainable from a radar system is independent of the altitude of the sensor platform and increases with the length of the antenna that transmits and receives the microwave pulses. In order to keep antennae reasonably small, a technique known as synthetic aperture radar (SAR) has been developed which applies a linear frequency modulation to a transmitted long pulse in order to simulate a train of short pulses. The technique then uses the Doppler shift of the reflected pulse due to the motion of the platform and a modified data processing to simulate a much longer antenna. The result is a higher resolution which is only limited by the power that the antenna is capable of transmitting.

35. The microwave spectrum is subdivided into various bands, each of which is referred to by a single letter character and is determined by a specific range of frequencies, as follows:

Band name	Band limits (GHz)	Band name	Band limits (GHz)
P-band	0.225-0.390	K-band	10.90-36.00
L-band	0.390-1.550	Q-band	36.00-46.00
S-band	1.550-4.200	V-band	46.00-56.00
C-band	4.200-5.750	W-band	56.00-100.0
X-band	5.750-10.90		

For airborne radar missions, which account for the bulk of the microwave data gathered world wide to date, the most used bands have been the X-band and the K-band. For the satellite radar systems of the 1990s, the predominant frequency will be the C-band.

B. Data acquisition and processing

36. At present, the possibility of acquiring microwave data for a specific application is almost exclusively limited to airborne radar missions. These missions can be planned to enhance the information content of the desired features on the imagery by selecting the time of year, to some extent the view angle of the radar, the direction of the flight lines and the separation between the latter. However, since the cost associated with these missions is high, it is necessary during the planning stage to establish that the data are in fact necessary.

37. As space-borne radar becomes operational, the cost of data acquisition will greatly decrease, but so will the flexibility in selecting the viewing parameters. Whichever type of radar platform is selected, the success of any microwave remote sensing project depends to a large degree on the quality and timeliness of the data. The achievement of this goal depends upon a thorough analysis of the objective of the project, including a determination of whether radar data by itself or possibly combined with visible or infra-red data, contribute significantly to that objective.

38. Once the desirability of acquiring microwave data has been established it is necessary to determine the availability of the required or preferred sensors. The choice of wavelength band has the most significant effect on the return signal; it determines the discrimination level of the features to be observed. Most available radar systems operate in the X, C or L-band. The following illustrates the type of information that could be obtained from the use of each of these three systems in a vegetation survey. The shorter wavelength of X-band data would respond to the vegetation canopy and provide information about the biomass or structure of the vegetation. The C-band has a wavelength that is only slightly longer and would provide more information about the internal structure of the vegetation and to a lesser degree on the nature of the soil. For the L-band, with a longer wavelength, the radiation would penetrate deeper into the vegetation canopy and provide information primarily about the soil.

39. The capability to undertake a project, in terms of equipment and personnel, needs to be carefully assessed. The amount and type of products to be acquired need to be accurately identified, taking into consideration the institution's ability to process, analyse and store the data and other products. In addition to the collection of radar data, a detailed ground truth programme should be prepared to support the analysis of the data. Whenever possible, the ground truth gathering exercises should be conducted simultaneously as the radar data are being collected. Finally, a detailed cost analysis of the airborne and ground based segments for data acquisition, including their processing and analysis, should be performed.

40. As is the case with visible and infra-red remote sensing, microwave data are seldom used in isolation. A complete project would include some or all of the following elements: multi-frequency, multi-date, and multi-polarized radar data, base maps and air photographs or satellite visible/infra-red imagery. A quick-look capability of the microwave data being acquired can be extremely useful. This capability would identify any areas that need to be revisited by the airborne radar when the target features respond differently from what was expected.

41. The merging of radar imagery with imagery from other sensor systems has proved to be useful in improving the identification of land-cover elements present in an observed area. The use of visible and near infra-red images from the SPOT satellite (France) with images from SIR-A have shown that the radar backscatter information allows discrimination between paddy fields and sugar palm plantations which is not possible using the SPOT data alone. On the other hand, the discrimination of orchards and bushes is made from the SPOT data and is not possible using SIR-A data only.

C. Applications to tropical forests

42. Tropical forests are one of the Earth's most valuable resources. From an ecological perspective, they play a major role in the hydrological cycle and in recycling atmospheric carbon dioxide. They stabilize soil and prevent excess runoff of silt and dissolved substances into streams. Their effects on climate through energy and water exchange with the atmosphere are not well understood but are expected to be significant. Much of the Earth's species diversity is represented by the plants and animals which make up tropical forest biomass.

43. For most tropical countries deforestation has become a drain of an increasingly valuable resource. Local and overseas interests alike have over-exploited forest resources. While it is apparent that improved management of tropical forests requires substantial economic, political and institutional changes, it also requires additional information about the forests themselves and changes which are happening in and around them. Much of the additional information can be supplied by satellite and airborne remote sensing systems (with adequate field checking).

44. The advantage of radar remote sensing represented by its ability to operate independently of solar illumination and in areas of persistent cloud cover, such as the tropics, was demonstrated in the successful completion of the first imaging radar mission conducted by the University of Kansas (United States) over Darien Province of Panama in the late 1960s. Numerous studies of the application of radar remote sensing in the tropics have been carried out since then. Most of the tropical experience with radar has been in the form of "on-the-job learning" as part of operational surveys, in contrast with temperate latitude studies, which have been generally of a formal research nature.

45. Airborne synthetic aperture radar (SAR) and real-aperture side-looking airborne radar (SLAR) imagery of tropical areas around the globe has been acquired during more than 50 major commercial reconnaissance surveys, employing mainly X-band SLAR and SAR systems. Regional and nationwide surveys in South-East Asia, Africa and Central and South America to date exceed more than 15 million square kilometres in areal coverage. With the exception of recent projects involving the use of digital SAR data, image analysis procedures employed on these data have relied mainly upon visual interpretation techniques.

46. The development of digital SAR imaging and processing technology during the 1980s has resulted in advanced operational systems that can provide spatial resolution of up to 6 metres, with high geometric and radiometric quality. Numerous regional and national tropical vegetation surveys have shown the applicability of radar data to specific types or conditions of vegetation. In particular, major vegetation formations, including savanna, dense and open tropical forest and woodlands, have been identified on radar imagery. Published reports have also shown that mangrove forest environments can be mapped accurately because of their strong radar backscatter compared to the surrounding forest stands. Radar imaging has also been successfully used for mapping a variety of forest types, including swamp forests, high scrub forest, tea trees, eucalyptus forest and palm forests, as well as pi[illegible], banana and rubber plantations.

47. The aircraft of the Jet Propulsion Laboratory (JPL) (United States), using the C, L and P-bands, completed a series of flights over Belize in 1990 allowing a direct comparison of the usefulness of the three bands for tropical forest applications. The results showed that the image contrast for forested/deforested boundaries increased with wavelength. There is also a decrease in mean reflectivity at C-band wavelengths with increasing angle of incidence of the microwave radiation. This effect could prove useful as a discrimination element for data available over a range of incidence angles, as will be the case for Canada's RADARSAT data.

48. Although C-band data will be the most abundant data to be obtained from operational systems for the next decade, they are not the best data for tropical forest applications. Results from the limited C-band data available show little discrimination between undisturbed tropical forests and older deforested areas or dense plantations. The results also indicate that C-band radar rarely penetrates through foliage in closed moist forests. The experiments of the JPL mission referred to above also show that the P-band has the greatest potential to differentiate between the canopy's foliage, the standing timber and the surface beneath the forest. These differentiations improved when the polarization of the incident and reflected radiation was considered.

D. Applications to hydrology

49. Because of its capability to measure directly the state of the system, microwave remote sensing offers unique possibilities for weather, climate and hydrological studies. Measurements of water vapour content, snow water equivalent and soil moisture are examples of atmospheric and hydrologic state variables that can potentially be measured by microwave sensing. In other regions of the EM spectrum, except for thermal sensing, the geophysical variables must be inferred since they cannot be measured directly.

50. Remote sensing for atmospheric and hydrologic processes is traditionally carried out at frequencies near the peaks and valleys of the atmospheric attenuation curve. Measurements near the resonant peaks are used primarily to determine atmospheric temperature or water vapour. Such measurements (around 22 GHz) can either provide estimates of the total water content in a column of the atmosphere or be used to correct for the effects of atmospheric attenuation in the sensing of other parameters. Measurements in the 50 to 70 GHz range (oxygen resonance lines) are used to obtain temperature profiles of the atmosphere.

51. Measurements in the valleys of the atmospheric attenuation curve are ideally suited for monitoring the Earth's surface. Such measurements include sea surface temperature (SST), snow cover, concentration of sea ice and soil moisture. For example, SST measurements have been made at 18 and 37 GHz, snow cover at 37 GHz and soil moisture at 6 and 1.4 GHz. At the lower-frequency (i.e., longer-wavelength) end of the microwave spectrum, the radiation emitted or reflected by matter is generally determined by its bulk dielectric properties. This implies that the measured radiation contains information about the inner structure of the bodies being sensed.

52. Passive and active microwave observations can provide direct measurements or estimates of rainfall rates. The physical basis for passive measurements fall into two régimes: absorption and scattering. In the absorption régime, rainfall is observed through the enhanced microwave emission associated with the raindrops against a cold background. This technique is only applicable over the surface of the ocean. In the scattering régime, rainfall is observed through enhanced microwave scattering (due to the raindrops) which can be measured against any surface background. For active microwave measurements, the physical basis is also found in the scattering behaviour of the radiation with the raindrops.

53. Soil moisture can be defined as the temporary storage of precipitation within a shallow layer of the Earth that is generally limited to the zone of aeration or root zone. Although the amount of water in this layer may appear to be insignificant when compared to the total amount of water available on a global scale, it is this layer that controls the success of agriculture and regulates the distribution of precipitation between storm runoff and storage. In spite of its importance, soil moisture is seldom used in the prediction and monitoring of crop productivity and water resources because of the difficulty in its determination.

54. Soil moisture is highly variable both spatially and temporally as a result of the inhomogeneity of soil properties, topography, land cover and non-uniformity of rainfall and evapo-transpiration. Soil moisture is difficult to measure, by any means, in a way that is representative of large areas; such measurements are only valid at the "point" where they are obtained. Although averages of point measurements of soil moisture are used to characterize an area, these averages seldom yield information that may be representative of other hydrologic processes (e.g., evapo-transpiration or runoff ground-water recharge).

55. Microwave measurements of soil moisture are based on the large contrast between the dielectric properties of liquid water and dry soil. For many hydrologic applications, changes in soil moisture may be more important than the actual absolute value of the soil moisture. Although not a truly operational technology, remote sensing of soil moisture has been shown to be feasible through a number of research projects. A great deal has been learned from those studies, but additional work is needed to define the optimal sensor configurations.

56. Evapo-transpiration is the combined loss of water through the process of evaporation from water surfaces and bare soil and transpiration from the canopy cover. The crucial role of evapo-transpiration at regional or global hydrologic scales has only recently begun to be understood. Climatic simulations using global models now demonstrate that precipitation is sensitive to regional evapo-transpiration magnitudes.

57. Known remote sensing techniques are not applicable for measuring evaporation and transpiration. The values and the rates of change of the latter depend on the initial soil moisture, atmospheric conditions, the characteristics of the surface and the incoming solar radiation. The evaporation rate is controlled initially by the availability of energy at the soil surface. As the soil surface dries, the rate decreases and is controlled by the transfer of water to the surface. Transpiration from a canopy depends upon the soil moisture available in the root zone and on the energy input into the system. Thus, evapo-transpiration values are

estimated from visible and infra-red measurements to identify land cover and to estimate photosynthesis rates as well as from microwave data to characterize the surface and to estimate soil moisture.

58. Snow has two major roles in the hydrologic cycle: (i) snow melt is the principal source of water for runoff and soil moisture recharge at high latitudes and high altitudes; and (ii) snow cover influences the global climate; even small areas in mid-latitude mountains may also be sensitive indicators of climate change. Visible and infra-red data do not provide accurate estimates of snow water equivalence (the crucial value in snow hydrology), partly because snow depth cannot be measured in this spectral range. In addition, because rapid snow melt often occurs in cloudy weather it is important to be able to have all-weather capability to determine the snow-covered area.

59. Microwave remote sensing can provide information on the snow pack properties of most interest to hydrologists: snow-covered area; snow/water equivalent; and the presence of liquid water in the snow pack, signalling the onset of the melt. The potential of microwave sensing is based on its sensitivity to the presence of even minute quantities of liquid in the snow which drastically change its dielectric coefficient.

E. Radar applications in the ECLAC region

60. Brazil's RADAM project (1970-1976) is the largest radar mapping programme executed to date using an airborne system. Initially designed to cover the Amazonia region, the project was later expanded to include the entire country (8.5 million square km). The project produced mosaics of Brazil at the scales of 1:440,000 and 1:250,000; these were thematically interpreted to produce 25 inventory reports on natural resources as well as maps on geology, soils, vegetation and geomorphology of the entire country.

61. Current research at INPE is focusing on microwave remote sensing applications to dynamic events (floods, hurricane effects, ocean wave behaviour, soil moisture and crop productivity models). A project of particular interest at INPE aims at determining the interaction mechanisms between the microwave radiation and bare soils and crops in two flood plain areas in north-eastern and south-eastern Brazil. The project is currently based on the use of airborne radar imagery; there are plans to use ERS-1, JERS-1 and RADARSAT satellite data in the project in the future. Through a separate project INPE is designing a portable microwave reflectometer to measure, in the field, the moisture content of the soil surface layer.

62. INPE also plans to use multitemporal/multisensor data for the evaluation of a Brazilian rain-forest area. The project will integrate data from the RADAM project, Landsat's MSS and TM scanners, ERS-1, SIR-C and RADARSAT to determine the stages of deforestation, the expansion of farming activities and the regrowth of vegetation of the rain forest.

63. A co-operation programme betwen Chile and Germany will result in the establishment of an ERS-1/VLBI (very long base interferometry) station to be

located at Chile's O'Higgins base in the Antarctic. The installation and main operation of the station will be the responsibility of German scientific institutions; Chile will provide logistic support and will participate in the operation of the station. The Chilean scientific support will be provided by the universities and institutions associated with national resources studies and Antarctic programmes; those establishments will each be responsible for a specific research or applications project.

64. The planned Chilean national projects include the measurement of continental drift (using VLBI) and the use of ERS-1 data for oceanographic and wave studies, determination of wind speeds and direction, ice dynamics studies, mapping of geological formations, mapping of ocean currents and wave analysis, coastal cartography and continental bathymetry. Possibilities of regional co-operation are also anticipated, particularly in projects that could include the entire South America region once the ERS-1 receiving stations at Cotopaxi (Ecuador) and Cuiba (Brazil) are established. Such projects would include regional tropical forest studies, oceanography and hydrology. At the subregional level, co-operation projects could include the study of Andean water resources in the geographic region encompassing northern portions of Argentina and Chile and the southern portions of Bolivia and Peru.

65. Since 1972, Peru has conducted four major microwave projects using airborne radar imagery acquired by several private companies. Due to technical flaws in the acquisition of the data, the results from the first project could not be properly referenced to existing cartography. The two subsequent projects provided imagery, at scales of 1:250,000 and 1:100,000, that was useful for applications to forestry, geology and hydrology, including, e.g., the pre-engineering studies of the location of the trans-Amazon oil pipeline and the electric power lines in the Andes region. The interpretation and analysis of the data were conducted by Peruvian technicians using analog methods.

66. As part of the joint Peruvian/Canadian remote sensing project TELEDETECTION II, the Comisión Nacional de Investigación y Desarrollo Aeroespacial (CONIDA) and the Canada Centre for Remote Sensing (CCRS) are planning to utilize airborne radar imagery to be acquired over Peru in 1991 in preparation for the use of RADARSAT data on an operational basis. The project includes the acquisition of equipment for digital processing and analysis of the data. The timely experience obtained by CONIDA and a number of other Peruvian institutions that plan to participate in the project will enable Peru to utilize data from ERS-1, JERS-1 and RADARSAT in meeting the objectives of its national remote sensing plan, which is currently being updated.

67. Microwave remote sensing can also make important contributions to the monitoring catastrophic events and the support of relief operations through its capability to gather information under all-weather, day or night conditions. Recent applications of this technology include the mapping of oil spills in the ocean and of the extension of flood areas, the assessment of damage caused by severe storms, hurricanes and tornados and the monitoring of the impact of major geologic events such as volcanic eruptions and landslides. The ability of radar to penetrate smoke also gives it a distinct advantage in mapping active forest fires.

68. The Shuttle Imaging Radar (SIR-A) experiment, flown on board NASA's Space Shuttle in November 1981, was a SAR instrument operating in the C-band (wavelength of 23 cm), with an incidence angle of 47°; its primary mission was to obtain observations for geological applications. The data were recorded on board the Shuttle during two and a half days of operations, and the tapes were returned to earth for processing. Data were acquired over about 10 million sq km, mostly over land areas. In October 1984, the Shuttle Imaging Radar-B (SIR-B) was operated during an eight-day Shuttle mission. SIR-B operated at the same wavelength (23 cm) as SIR-A, but could acquire imagery at various angles, ranging between 15° and 65°, thereby allowing a systematic study of the usefulness of different incidence angles for mapping different surface features. Through the choice of orbital altitude, observations could also be made of the same area on consecutive days.

69. The next experiment in the Shuttle Imaging Radar series will be the SIR-C system, which will be carried on three Shuttle missions now planned for 1993, 1994 and 1995. In addition to being able to operate, like SIR-B, at a range of incidence angles, SIR-C will be able to operate at three different bands (C, L and X). SIR-C will also be able to make observations using both horizontally and vertically polarized beams, providing another dimension for distinguishing between different types of ground surfaces.

F. Future radar satellites

70. In 1991, ESA will launch the ERS-1 satellite with a number of microwave sensors on board. The primary purpose of the mission will be to increase the understanding of ocean processes, to monitor the polar regions and to contribute to the World Climatology Research Programme. The primary instrument on ERS-1 will be the Active Microwave Instrument (AMI), which can operate as an imaging radar and either a wind or a wave scatterometer. It will operate in the C-band and its beam will be directed downward at an incidence angle of 23°, which is optimum for oceanographic applications but not ideal for land observations. The satellite orbit is such that the same ground area can be covered every three days. Operating as an imaging radar, the instrument will cover a swath 80 to 100 km wide with a maximum resolution of 30 m.

71. Operating as a wind scatterometer, AMI will cover a 400 km swath with a resolution of 50 km and will measure wind speed within the range of 4 to 24 m/s with an accuracy of 0.5 to 2 m/s, depending on wind speed; it will measure wind direction to an accuracy of 20°. Wind direction will be determined by measuring the reflectivity of each resolution element from three directions: obliquely ahead of the satellite path, to the side of the satellite path and obliquely behind the satellite path. The intensity of the three signals indicates the wind speed, and the differences indicate the wind direction. Operating as a wave scatterometer, AMI will measure the length and direction of ocean waves in 5 by 5 km squares every 200 to 300 km along the satellite path. Wavelengths of 100 to 1,000 m will be measured to an accuracy of 25 per cent and the direction will be measured to an accuracy of 20°.

72. In addition to AMI, ERS-1 will also carry a radar altimeter and a laser retro-reflector. The radar altimeter, operating at a wavelength of about 2 cm, will look vertically downwards and will be used to measure the average wave height, the wind speed and the meso-scale ocean topography. It will also be used over ice-covered waters to measure surface topography and to determine ice type and water/ice boundaries. The radar altimeter will have a resolution of 2 to 20 km depending on the sea state and will measure heights between 1 and 20 m with an accuracy of 0.5 to 2 m depending on wave height.

73. ERS-1 will also carry an Along Track Scanning Radiometer (ATSR) operating in three bands in the thermal infra-red spectral region at 3.7 µm, 11 µm and 12 µm and looking at each point on the surface from two directions, from vertically above and at an incidence angle of 50°, thereby providing a total of six measurements for each point on the surface. The difference between the oblique measurement and the vertical measurement will provide an indication of atmospheric absorption, while the differences between the various wavelengths will provide an indication of atmospheric water vapour content. The intensity of the signals, when corrected for atmospheric effects, will indicate the sea surface temperature. The system will have a resolution of approximately 1 km and will be able to observe temperature differences of 0.1° C with an absolute accuracy of 0.5° over larger areas. It will be able to function in a cloud cover of up to 80 per cent.

74. Canada's RADARSAT will carry one SAR instrument that will operate in the C-band with multi-mode single polarization. RADARSAT will be capable of imaging swaths 35 to 500 km in width with associated resolutions of 10 to 100 m. The instrument has been designed for imaging capability at a variety of incidence angles (approximately 20° to 50°). The spacecraft has been designed for a five-year lifetime and is scheduled for launch in December 1994. The orbit is planned at 800 km, sun-synchronous, dawn-to-dusk, with a 24-day repeat visit and a three-day sub-cycle. The SAR antenna will point North but the spacecraft will be capable of rotating 180° about its yaw axis in order to obtain images of Antarctica. Because it will carry on-board tape recorders, RADARSAT will be able to provide radar imagery of the entire globe.

75. RADARSAT mission operations will be co-ordinated by a mission management office (MMO) which will serve as an interface between the user community, the mission control facility and the ground receiving and processing facilities. MMO will monitor the entire data distribution, which will be carried out mainly by RADARSAT International, a private-sector corporation. The image products to be provided will be of the following three types: (i) geo-referenced products, i.e., standard images with systematic geometric corrections; (ii) geo-coded products, i.e., images that are resampled and rotated to conform to standard map projections; and (iii) special products, e.g., unprocessed signal data, single-look (full-resolution) real or complex image files and analysis of external calibration files. The image products will generally be available in both photographic and digital forms. The imaging modes for RADARSAT will include Standard (30 m resolution), Wide Swath (30-50 m resolution), Fine Resolution (10 m resolution), Extended (20-60 m resolution) and ScanSAR (50-100 m resolution).

76. RADARSAT has been designed as an end-to-end system with operational users in mind. For perishable data, such as those needed for navigation in the ice of the

Arctic, data will be gathered, processed, imaged, merged with ancillary data, Earth located and relayed to ships, all within four hours of satellite overflight. Similar capability will exist for monitoring real-time events such as floods and forest fires. For other applications, the turn-around times will be tailored to user needs; for agricultural applications, for example, a turn-around time of a few days would be typical.

77. As part of the International Space Station programme, the United States will be launching two polar platforms, which will be used in conjunction with polar platforms launched by ESA and Japan and with a series of geostationary satellites to monitor the global environment. This will be part of the United States Earth Observation System (EOS), the purpose of which is to collect a consistent set of global environmental data over a period of 15 years in order to study global changes such as those due to the greenhouse effect and to changes in the ozone layer. An Advanced Microwave Sounding Unit (AMSU) for atmospheric water vapour and temperature profiles and an Advanced Microwave Scanning Radiometer (AMSR) for measuring sea surface temperature and observing ice, snow and precipitation are also being planned as part of the system.

78. In the mid-1990s, ESA will be participating in the International Space Station along with the United States, Canada and Japan. The ESA components will include a European module attached to the main space station and the Columbus Polar Platform currently scheduled for launch in 1997 into a near polar orbit. Among the remote sensing systems being considered for use on the Polar Platform are an imaging radar system, a radar altimeter and a scatterometer, along with a number of systems operating in the visible and infra-red bands. Data from the Polar Platform will be transmitted either directly to ground stations or via ESA data relay satellites when the Platform is outside the range of a ground station, thus ensuring a global coverage capability.

79. A major purpose of the Polar Platform microwave sensors will be to ensure continuity with the systems scheduled to operate in the early 1990s, in particular with ERS-1 and ERS-2; its priority will therefore be ocean observations. However, the imaging radar would have a variable incidence angle, allowing the observations of land areas at high incidence angles for geomorphological studies as well as observations of ocean features at low incidence angles. The system would have several operating modes, ranging from high-resolution (10 m) imaging of a narrow swath (30 km) to low-resolution (1 km) imaging of a wide swath (500 km). Like ERS-1, the Polar Platform radar would operate in the C-band. The scatterometer, also operating in the C-band, would be designed primarily for measuring surface wind speed.

Annex I

PROGRAMME OF THE WORKSHOP

Date	Time	Subject	Speaker
Monday 19 November	9.30 a.m.	Opening ceremony	
		Welcome addresses:	
		Instituto Nacional de Pesquisas Espaciais	M. R. Mucio
		European Space Agency	J. Lichtenegger
		United Nations	S. Camacho
	9.30-10.15 a.m.	Keynote address: Requirements for microwave remote sensing in Latin America and the Caribbean	J. Massa (INPE)
		Chairman: R. Coloma (Peru)	
	10.30-11.15 a.m.	Overview of microwave remote sensing	J. Lichtenegger (ESA)
	11.15 a.m.-noon	Principles of microwave radiometry and microwave interaction mechanism	J. Lichtenegger (ESA)
		Data acquisition and processing	
		Chairman: R. Coloma (Peru)	
	1.30-3.30 p.m.	Radar instruments and related measurement possibilities	J. Lichtenegger (ESA)
	3.45-4.30 p.m.	Developing SAR capability including mission planning and data acquisition	K. Link (Intera Kenting)
	4.30-5 p.m.	Discussion	
Tuesday 20 November		Integration and analysis of data from different sensor systems	
		Chairman: W. Atiba (Jamaica)	
	9-9.45 a.m.	Radar image characteristics, processing and analysis	J. Lichtenegger (ESA)

Date	Time	Subject	Speaker
	9.45-10.30 a.m.	Merging of radar imagery with imagery (data) from other sensor systems	J. Lichtenegger (ESA)
	10.45-11.30 a.m.	Use of microwave and optical data for land use mapping: case study in Tunisia	J. F. Dallemand (FAO)
	11.30 a.m-12.15 p.m	Multi-sensor analysis for land use mapping	J. F. Dallemand (FAO)
		Land applications (potential and limitations)	
		Chairman: E. T. Engman (United States)	
	2-2.45 p.m.	Microwave remote sensing applied to hydrological problems: ongoing projects and prospects	Hermann Hux (INPE)
	2.45-3.30 p.m.	A review of radar remote sensing for tropical forest management	K. Raney (CCRS)
	3.45-4.30 p.m.	Microwave remote sensing of tropical forests: new applications within Peru's remote sensing programme	R. Coloma (CONIDA)
	4.30-5.15 p.m.	Applications of microwave remote sensing to environmental monitoring (and catastrophic effects)	K. Link (Intera Kenting)
Wednesday 21 November		Weather, climate and oceanographic applications (potential and limitations)	
		Chairman: J. Massa (Brazil)	
	9-9.45 a.m.	Microwave sensor applications for weather, climate and hydrology	E. T. Engman (NASA)
	9.45-10.30 a.m.	Oceanographic applications of radar data (sea-state, ocean circulation and ocean surface topography)	J. Lorenzetti (INPE)

Date	Time	Subject	Speaker
		Past experiences	
	10.45-11.30 a.m.	Practical applications of SEASAT, SIR-A and SIR-B data	E. T. Engman (NASA)
	11.30 a.m.-12.15 p.m.	Airborne radar experience from a Canadian perspective	K. Raney (CCRS)
		Currently approved programmes: instrumentation, measurements and application possibilities	
	12.15-1 p.m.	Canada's RADARSAT programme	K. Raney (CCRS)
		Chairman: C. Patillo (Chile)	
	2-2.45 p.m.	ESA's ERS-1 programme	J. Lichtenegger (ESA)
	2.45-3.30 p.m.	Reception and processing of ERS-1 data: application possibilities for the region	M. Araya (Chile)
		Future programmes	
	3.45-4.30 p.m.	The Earth Observing Systems	E. T. Engman (NASA)
	4.30-5.15 p.m.	The Polar Platforms	J. Lichtenegger (ESA)
	5.15-6 p.m.	A regional centre for space science and technology education	A. Abiodun United Nations
Thursday 22 November	9 a.m.-12 noon	Working Group session - microwave remote sensing: Chairman: K. Raney (Canada) Rapporteur: S. Camacho (United Nations) (a) Data accessibility and availability (b) Applications development (c) Required education and training	

Date	Time	Subject	Speaker
	2-5.30 p.m.	Visit to INPE's space facilities	
Friday 23 November	9 a.m.-12.30 p.m.	Conclusion and observations of the Working Group session	
	12.30-1 p.m.	Closing ceremony	United Nations/ FAO/ESA/Brazil

Annex II

SELECTED PARAMETERS OF ALL CIVILIAN SAR SATELLITES

	SEASAT (United States)	ALMAZ (USSR)	ERS-1 (ESA)	J-ERS-1 (Japan)	SIR-C (United States)	ERS-2 (ESA)	RADARSAT (Canada)	EOS (United States)
Operation period	1978	1990-1993	1991-1993	1992-1994	1993, 1994, 1995	1994-1996	1994-1999	1999 (?)-
Radar bands	L	S	C	L	C, L, X	C	C	C, L(X)
Polarimetry					yes			
Swath width (km)	100	30-300	80	75	15-90	80	50-500	50-500
Resolution (m)	25	15-300	30	18	30	30	10-100	10-100
Incidence angle (°)	22	40-60	23	39	15-55	23	20-59	15-55
Maximum North latitude (°)	72	73	80	80	53	80	90	
On-board recorder		yes		yes	yes		yes	yes

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COMMITTEE ON THE PEACEFUL USES OF
OUTER SPACE

APPLICATIONS OF SPACE TECHNOLOGY TO FLOOD MONITORING AND CONTROL

Note by the Secretariat

1. The Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), in the report on the work of its fourth session, made a series of recommendations concerning the preparation of reports and studies by the Secretariat and the compilation of information from Member States (A/AC.105/456, annex II, paras. 4 and 6).

2. The Working Group recommended, in paragraph 5 (b) of its report, that a few specific studies should be carried out to demonstrate the potentials of space technology, including a study on flood monitoring and control. The Working Group recommended that, as a first step, information on some of the subjects might be provided as part of the United Nations efforts in conjunction with International Space Year.

3. The report of the Working Group was adopted by the Scientific and Technical Sub-Committee at its twenty-seventh session (A/AC.105/456, para. 21), and the recommendations were endorsed by the Committee on the Peaceful Uses of Outer Space at its thirty-third session 1/ and by the General Assembly in its resolution A/45/72 of 11 December 1990.

4. The present study was prepared using a variety of national and international sources. These sources are listed in the selected bibliography at the end of the study.

5. The following summary of the study has been translated into all the official languages of the United Nations. The full study, contained in the annex to the present document, is being distributed only in the language in which it was prepared (English) because of its technical character.

SUMMARY OF THE STUDY

6. Images of the Earth acquired by remote sensing satellites offer an effective and economic means for large-area surveys of lakes, rivers and other water bodies and for monitoring flooding of these bodies. While satellite remote sensing has, for some purposes, replaced aerial photography and ground surveys, it should be seen as complementary to such traditional methods for gathering data for flood management.

7. The major advantage of satellite remote sensing for flood mapping, monitoring and management lies in its ability to cover large areas quickly and economically, to repetitively monitor changing situations and to survey remote areas where access on the ground or by air may be difficult. Ground surveys can provide detailed and quantitative information over small areas, and that information can be used to assist the process of satellite image interpretation.

8. Satellite remote sensing, with its repetitive coverage, is particularly useful for monitoring the rapidly changing extent of surface water in floods. Water surfaces are easily distinguished from land on remote sensing imagery, and wet, low-lying ground can generally be distinguished from higher and dryer ground during floods and for several days following the recession of flood waters. When data have been obtained at different times during a flood, comparison of the images provides information on flood dynamics. Such information is valuable not only during the flood for organizing flood relief efforts, but also afterwards for assessing the damage caused by the flood and for planning future flood management efforts. Satellite data are often a unique source of information during floods, since other sources of information are likely to be disrupted.

9. In addition to mapping and monitoring floods, remote sensing can play an important role in the planning and monitoring of activities related to flood protection and relief. These ongoing flood management activities include mapping normal conditions, accumulating and analysing data on the frequency of floods of various magnitudes, mapping the watershed and flood plain and monitoring land use in the flood plain. Remote sensing imagery is also valuable for planning flood control levees and other water control structures as part of flood plain management, in particular for designing structures to ensure that they have sufficient capacity and strength to contain the expected floods, but are not unnecessarily expensive.

10. An appreciation of the use of remote sensing data, in combination with other types of data, for flood management requires an understanding of the process of flooding. Flooding normally begins with higher than normal rainfall or snow-melt, leading to large quantities of surface run-off, which accumulates in watercourses to the extent that they overflow their normal banks. Factors that determine the frequency, severity and duration of floods include rainfall intensity, extent and duration, the size and slope of the drainage basin, the soil type, the land use and vegetation cover over the area, the pre-existing moisture content of the soil, and the size, shape and slope of the normal river bed and flood control structures.

Remote sensing images, interpreted in conjunction with other data, can be used for studying all of these environmental and river basin characteristics.

11. Clearing of land in a watershed, particularly on slopes, can substantially increase the volume and rate of run-off during and following rainfall, thereby increasing the risk and severity of flooding. Remote sensing provides an effective means for the regular monitoring of deforestation, the extension of cultivation and the removal of natural vegetation. Increases in the sediment carried by rivers and streams as a result of erosion can often be observed on satellite imagery. That sediment can reduce the capacity of reservoirs downstream and build up in river beds, thus increasing the risk of flooding.

12. The damage caused by a flood will depend not only on the magnitude of the flood, but also on the distribution of the population in the flood plain, land use patterns, flood control structures, flood warning systems and emergency flood management arrangements. The use of remote sensing satellites for mapping flood plains and for maintaining up-to-date information on land use and settlement patterns in the flood plain can make an important contribution to minimizing human suffering and economic losses in the case of floods. Current land-use maps are also essential for planning the construction of flood control structures.

13. A knowledge of the characteristics of a river basin can be used to develop predictive models of floods. As water accumulates in a river valley following heavy rains or snow-melt, the swelling and overflow of the river can be observed by remote sensing or ground monitoring. A model of the river basin can be used to calculate the water height and volume of flow as a function of time and place along the course of the river. In particular, the models are used to predict the maximum water levels and the time at which they will occur at points of concern. The height and time of passage of the flood crest and the rate of recession of flood waters are particularly important predictors for emergency flood management purposes.

14. Meteorological satellites also provide data that are an important input to flood prediction systems. Satellite measurements of cloud cover, cloud temperature, atmospheric temperature and water vapour distribution are used to predict rainfall several days in advance. If the response of a river basin to rainfall is known, predictions of heavy rainfall can be converted into flood predictions and used to organize evacuations of threatened areas, mobilization of health and rescue facilities and other flood relief efforts. Meteorological or remote sensing satellite observations of snowpack and ice conditions also provide an important input to flood prediction models.

15. While quantitative computer models of flood dynamics offer the best predictions, simple models often allow useful forecasts of the risk, the timing and the severity of flooding at crucial points based on water levels at a point upstream. When a single point upstream is not adequate for forecasting purposes, flow measurements from several stations can be used. With the more complex models, flooding can be predicted longer in advance based on predictions or measurements of precipitation and a knowledge of the characteristics of the river basin. These models are based both on hydrological theories and on empirically determined

relationships between the various meteorological and hydrological factors. Flood warning systems can therefore vary in complexity from a simple network of manual water-level monitors to complex systems of automatic meteorological and hydrological sensors feeding data into computer models. The comparison of model predictions with actual flood observations can be used subsequently to improve the models.

16. In addition to existing remote sensing satellites that make observations in the visible and infrared portions of the spectrum, satellite radar systems can also be used for mapping and monitoring. A major advantage of radar systems is their ability to make observations when cloud cover or darkness prevents conventional observations. While quantitative interpretation of radar data is a rather complex process that still requires development work, interpretation of some features related to flood management has been demonstrated. The satellite radar systems being developed for launch in the next few years will increase knowledge of the applications of radar to flood management and will undoubtedly contribute to more effective flood management programmes.

17. The existing and planned remote sensing and meteorological satellites will be generating an increasing amount and variety of data. Processing and interpreting this volume of data is already a major problem, and the problem is going to grow. International co-operation, co-ordination and planning can help to promote the wide and effective use of remote sensing data for flood management purposes.

Notes

1/ Official Records of the General Assembly, Forty-fifth Session, Supplement No. 20 (A/45/20), para. 30.

Annex

APPLICATIONS OF SPACE TECHNOLOGY TO FLOOD MONITORING AND CONTROL

Study by the Secretariat

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INTRODUCTION

1. The distribution of water on Earth is highly uneven, with most of the water (97.4 per cent) in the oceans. Only a small fraction (2.6 per cent) of the total amount of water is on land, and most of that water is unavailable because it is confined as ice, snow or groundwater. Only about 0.014 per cent of the Earth's total water is fresh water readily available to human beings and other organisms. This fresh water is in a state of constant flux, running off the land into the oceans, evaporating from the surface of the land and oceans, condensing into clouds and falling as precipitation.

2. While shortages of available fresh water pose major problems for most places on Earth, either occasionally or most of the time, excesses of water, in the form of floods, also cause enormous suffering and economic losses. Most commonly, floods occur when unusually heavy rainfall causes water to accumulate on the land faster than it can be carried away by the normal drainage system, therefore making the water overflow the natural or artificial confines of rivers, lakes, streams and other bodies of water, or accumulate in low-lying areas.

3. Along rivers, on either side, deposition of sediment during the periodic flooding of the river creates flat strips of land called flood plains. Flood plains that are inundated every year or two are commonly referred to as active or living flood plains. The unconsolidated sediment, mostly clay and silt, that settles out during flooding is derived from the erosion of the land around the river higher in the drainage basin. Because of the high clay content, flood plains commonly have poor surface and subsurface drainage, but none the less provide rich agricultural lands that in many parts of the world are highly populated. Their main disadvantage stems from the natural hazard of flooding, sometimes on a catastrophic scale. A list of major floods within the last century is given in appendix I to the present study.

4. Because floods are so damaging, major efforts are made to prevent them and to protect humans and property from damage in floods that cannot be prevented. Flood management refers to all efforts to control floods and to reduce the damage they cause. It includes the construction of flood control structures, the planning of land use in flood prone areas, preparation of emergency measures in case of flood and flood relief operations. Effective flood management requires both current and historical information on weather, land forms, land use, population distribution and other factors. Satellite technology, and in particular remote sensing, can provide important information for use in flood management.

5. During floods, repetitive satellite imagery may be a unique source of information on the extent and dynamics of flood water advance and retreat. At other times, satellite imagery can be used for flood plain mapping and flood management planning. Remote sensing satellites that provide detailed imagery of the ground, and meteorological satellites that provide data for weather forecasts and less detailed but more frequent images of the ground, provide complementary information.

6. Communication satellites can also play an important role in flood management, particularly when floods disrupt normal communication lines. Communication satellites can also be used to relay data from remote automatic meteorological and hydrological monitoring stations to a central station for analysis and flood prediction and monitoring. The present study, however, concentrates on the use of remote sensing and meteorological satellites in flood monitoring and control.

I. INFORMATION REQUIREMENTS FOR FLOOD MANAGEMENT

A. Flood frequency and damage

7. Floods are regular annual events in many of the major river basins all over the world, causing great disruption and extensive losses through damage to agricultural crops and property, in addition to loss of life. One recent example is the enormous damage caused by the floods in Bangladesh in 1988 (see appendix I). The data available on flood damage in the Economic and Social Commission for Asia and the Pacific (ESCAP) region alone during the 1960s indicate that almost 100 million hectares of land was inundated, causing damage to 14 million houses and other buildings. Many of the rivers that run through India cause floods during the south-west monsoon period, while dwindling to mere trickles during other seasons.

8. A study carried out by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1973 estimated that each year, in the ESCAP region, river floods damaged or destroyed about 4 million hectares of land and crops and affected the lives of over 17 million people. It has been estimated that some 5 million Chinese lost their lives in floods between 1860 and 1960, floods that constituted two of the three most costly disasters in terms of human life (the third being an extended drought and famine in India). During the period 1977 to 1984, at least 133 floods involving loss of life occurred in 45 countries.

9. Floods appear in third place on the list of fatal disasters, but the calculations do not include floods caused by tropical cyclones, hurricanes and typhoons. Storm surges accompanying these storms onto low-lying coastal regions have caused some of the highest natural disaster death tolls on record, exceeded only by the death tolls in some river floods and drought-provoked famines.

10. Notwithstanding the experience gained over many years in studying the nature of floods and the tremendous efforts undertaken for their control, the damage caused by floods has been growing rapidly, primarily due to increasing settlement of flood plains, expansion of agriculture onto flood plains and deforestation and other environmental degradation of watersheds causing increased run-off.

11. Satellite observations can make an important contribution to the assessment of the magnitude of floods and the amount of damage caused. As ground-based information systems are often disrupted in cases of serious flooding, satellite images may provide the best data on the maximum extent of the flood and its duration in different areas. Even in cases where cloud cover prevents the

acquisition of imagery at the time of maximum flooding, image interpretation techniques can often be used afterwards to determine the areas inundated. Damage to crops from inundation is often visible on satellite imagery, and estimates of losses can be determined for planning or compensation purposes.

B. Causes of floods

12. The main causes of floods are:

(a) Heavy rains;

(b) Simultaneous peak flow in a major river and its tributaries;

(c) Inadequate and inefficient drainage of low-lying and flat areas;

(d) Snow-melt run-off combined with heavy rains;

(e) Typhoons, hurricanes and cyclones.

13. While heavy rains are the most common cause of flooding, other patterns of rain and snow can also cause serious floods. In large river basins, prolonged periods of moderate rain can result in flooding of the main river when all of the tributaries discharge large volumes of water into the main stream simultaneously. Rapid snow-melt and ice jams can cause floods that are especially dangerous because they are not necessarily preceded by heavy precipitation and hence may be difficult or impossible to predict. Even moderate amounts of warm rain falling on a deep snowpack, particularly if the ground beneath the snow is frozen and unable to absorb the moisture, can cause severe flooding.

14. Coastal flooding can be caused by storm-driven waves, exceptionally high tides, subsidence of coastal areas and tsunamis (seismic sea waves). Coastal flooding is of special concern because in many countries the population is concentrated along coastlines. Although exceptionally high tides rarely produce serious and widespread damage on their own, they may significantly increase the hazard of flooding in combination with even moderately severe storms. Hurricanes and other major storms produce most coastal floods. Tsunamis, caused by undersea earthquakes, landslides and volcanic eruptions, are low (less than a metre high) in the open ocean, but travel at speeds of up to 800 km/h and grow higher as they near land; tsunamis that hit land with heights of 18 to 30 m (60-100 ft) are not uncommon.

15. Human activities can also contribute to flooding. Deforestation, cultivation of steep slopes or poor soils and overexploitation and misuse of watersheds can lead to low water retention and faster surface run-off. In India, for example, the area susceptible to flood damage has increased from 19 million ha in 1960 to 59 million ha in recent years. In India, as in most of the countries which receive the south-west monsoon, more than 50 per cent of the annual rainfall occurs in periods that amount to less than 30 hours, a condition that is a major contributing factor to flooding.

16. In many areas, a decrease in the amount of water that can be absorbed into the ground, as a result of rapid silting of rivers and reservoirs, of urban and industrial expansion and of the construction of artificial embankments, has also increased the surface run-off and made the areas more prone to flooding.

17. Many of the causes and contributing factors of floods, including rainfall, snow-cover and land use patterns, can be studied using space technology. Meteorological satellite data are used for making quantitative estimates of rainfall and for monitoring the varying extent of snow-cover in watersheds, while remote sensing satellite data are used for monitoring changing land use and land cover patterns. Monitoring of the causes of floods allows assessments of flood risk and predictions of conditions likely to cause imminent flooding. After a flood occurs, analysis of satellite imagery acquired during the flood can provide a better quantitative and qualitative understanding of the causes of flooding in that particular watershed.

C. Flood plain management

18. Flood management starts with a knowledge of the flood plains. This knowledge provides answers to questions about the areas that may be affected by floods, the people and property situated in the flood prone areas and the probable frequency of floods of various magnitudes. Flood plain mapping provides the basis on which land-use planning can start, planning which aims at maximizing the long-term productivity of the flood plain while minimizing the risks due to floods. Effective flood management must include controls on the uses to which flood prone areas can be put so as to minimize risks to life and property during floods. Flood plain maps are also important for decision-making as floods develop, for example in deciding upon evacuations.

19. Flood management actions can be divided into three categories: actions in the watershed and river valley to prevent flooding; actions in the flood plain to limit the susceptibility to damage by flooding; and actions taken during floods to protect human life and welfare. While preventing floods is obviously the ideal solution, it is often not practicable to provide protection against all possible conditions and magnitudes of floods. A practical and effective flood management programme for a particular river will therefore generally include all three types of actions. The various flood management actions in these three categories are indicated in appendix II.

20. In the watershed, run-off can be controlled at the field level by such conservation techniques as bunding to induce groundwater recharge, water storage, kharif channels and embankments. These techniques often need to be supplemented by selective afforestation and water-conserving agricultural practices.

21. In the river valley itself, flood control can involve a variety of water control structures: (a) channel and drainage improvements; (b) levees (embankments, dikes, bunds) and flood walls; (c) diversions of flood waters and bypasses; and (d) reservoirs, detention and retarding basins.

22. In the flood plain, a flood management programme can include land use zoning, hydrological monitoring, development of flood prediction systems and establishment and maintenance of emergency flood response facilities.

23. In flood situations, flood management includes emergency strengthening of flood control structures, evacuating people, animals and valuables, mobilizing rescue and health facilities and monitoring and forecasting flood development.

24. Following floods, an assessment of the damage must be made and financial compensation paid to victims where possible, and data on the flood dynamics should be obtained in order to improve the flood management system for the future.

25. While these measures have resulted in significant levels of flood control in most developed countries and a few developing countries such as China and India, there is still a wide gap between the measures undertaken so far and the efforts needed to effectively control floods, particularly in practically all developing countries.

26. Increasingly, water development projects around the world involve large river systems from source to mouth, with a variety of users and interest groups competing for the available water. Socio-political considerations become important, and for many river systems these have international dimensions. Thus, the hydrologist and the land use planner are members of a multi-disciplinary scientific team assessing risks and evaluating the costs of alternative water- and flood-control strategies, and this scientific team must in turn work with other specialists assessing the socio-economic and political aspects of the alternatives. Given the broad implications of water development programmes and the important role of flood management in those programmes, educating the public in proper flood plain management is one of the prerequisites to minimizing flood damage.

27. With economic development and increasing population, both the hydrology of disastrous floods and the people and property at risk change rapidly. Expansion of agriculture through deforestation of hillsides, for example, which increases run-off and contributes to an increase in both the frequency and the severity of floods, was thought to be a factor in the floods in Bangladesh in 1988. Expanding urban areas can have similar effects. Enlargement of flood control structures such as dikes can also increase the risk of catastrophic flooding should they fail, especially when combined with the increased risk due to increases in population densities and economic activity in the regions protected by the dikes. Some of the worst recent incidents of loss of life due to flooding, including floods in France and the United States of America, have been caused by flash floods in valleys which have few permanent residents but which have become popular with holiday-makers at certain times of the year. Clearly, periodic reviews of both the flood risks and the land-use patterns are required if damage is to be minimized.

28. An important contribution of the hydrologist with respect to flood management is in providing information to allow the optimum design of water-control and water-use projects. Structures that are not strong enough to survive the extreme events that are likely to occur during their design life pose obvious dangers and may even increase the damage caused by a flood, while structures whose strength far

exceeds the stresses they will have to endure add greatly to the cost of flood management and may reduce the resources available for other important measures. Hydrologists, using historical data, assess the likelihood of various events occurring during the design life of the structures, co-operating closely with meteorologists in estimating the probability of weather events that such structures might have to withstand.

29. Flood management measures can be designed not only to reduce the harmful effects of floods, but also to use the flood waters. This could be achieved, for example, through development of crops that are more tolerant of prolonged inundation. Some of the flood-resistant rice varieties can withstand complete submergence for two to three weeks. Ensuring large transfer rates of surface water to underground storage structures will enable significant volumes of water during periods of high run-off to be saved for use in dry periods.

30. Diversion of excess water from one river basin to another that is dry or deficient in water is an additional way of using surplus flood waters. In areas with saline groundwater, controlled and diverted flood waters can also be used for diluting the saline groundwaters so that they can be used for irrigation.

31. Flood management systems require detailed and up-to-date knowledge of many aspects of the river basins. While detailed base maps, particularly of densely populated areas, are usually compiled from aerial photographs, satellite imagery can play an important role in keeping the knowledge up to date. Satellite images can be useful as base maps for monitoring adherence to land use restrictions, for planning flood control structures and for planning emergency operations during floods.

II. SCIENTIFIC ISSUES IN FLOOD MANAGEMENT

A. Flood forecasting

32. One of the major tasks of hydrologists is the forecasting of water levels in rivers and lakes, analogous to the weather forecasting done by meteorologists. Forecasts of water levels and of soil moisture have many applications in addition to their central role in dealing with flood phenomena. They are also used, for example, in controlling water levels, in apportioning available water among users (irrigation, navigation, power generation, urban water supplies, etc.) and generally in making optimum use of what is usually a limited and valuable resource. Flood forecasts are based on meteorological data, weather forecasts, upstream information and estimates (based on previous experience and analysis) of how a particular watershed will respond to precipitation.

33. Flood forecasting requires considerable advance work, including accurate mapping of the river system and its drainage basin, assessments of the role of run-off, of rainfall or snow-melt, and a measure of the capacity of the river to drain water from its basin. It also requires accurate measurements of rainfall and a knowledge of soil moisture and snowpack conditions. For river valleys, hydrologists have developed sophisticated flood forecasting models and are

collaborating with meteorologists to ensure access to real-time weather data that hydrologists need to provide flood forecasts as long in advance as possible.

34. Forecasting is an important requirement in flood management for such purposes as (a) planning the evacuation of people and livestock, advancing harvests, transporting movable items, etc.; (b) flood-proofing, mobilizing emergency services, orderly limitation of communication to emergency purposes; and (c) flood control by adjusting reservoir discharges to permit flood attenuation and emptying storm tanks and balancing ponds prior to the arrival of floods.

35. Among the numerous parameters required for accurate forecasting of floods, the distribution of rainfall in space and time has a marked influence on the behaviour of run-off. In many small basins, the time between rainfall and the peak flow (or flood) is very short, so that models that relate rainfall to river levels are particularly important. In such cases, weather conditions need to be continuously monitored to identify patterns that are likely to produce significant rainfall in the watershed. Existing soil moisture in the river basin may also be an important factor in predicting run-off and flood severity.

36. Studies in Canada, Japan, the United Kingdom of Great Britain and Northern Ireland and the United States have shown that flood forecasts and warnings can reduce damage by between 6 and 40 per cent. In principle, in the flood plains of large rivers, good hydrological forecasting services could reduce the damage from floods by up to 33 per cent. In practice, damage reduction due to flood warnings in these large flood plains is more typically 10 to 15 per cent, but even this figure gives high cost-benefit ratios.

37. Studies by the World Meteorological Organization (WMO) have indicated that, of those countries with a high risk of floods, some 15 have no warning system at all and another 40 or more have inadequate or only partial flood warning systems.

38. Meteorological satellites play a key role in flood prediction through their contribution to weather prediction. Satellite data such as cloud cover, cloud-top temperature, vertical temperature profiles, water vapour distributions, cloud-level winds and sea-surface temperature are put into computer models of the atmosphere to determine weather patterns over the next few days. Satellite observations of snow cover and soil moisture can also be important for run-off prediction.

B. Hydrological models

39. Hydrological models are essentially mathematical equations that represent the behaviour of natural hydrological phenomena. These models include run-off models, storage models and river flow models and may make specific predictions for defined circumstances or may indicate probabilities of events for a range of circumstances. Based on the available inputs and the desired outputs, an appropriate model can be chosen as a tool for prediction and management of floods under the conditions of interest.

40. In addition to general hydrological models, mathematical models representing hydrological and hydrometeorological processes have been developed specifically for application in the field of flood hydrology. For some hydrological problems, the type of model required is more or less obvious, e.g., probabilistic models for flood frequency estimates, or stochastic time-series for generating long-term synthetic stream-flow data. The physically based models use information from topographical, geological and soil maps and other information on vegetation and land use distribution. They can also use satellite images and other remotely sensed information, including continuously updated data on watershed conditions.

41. Of greatest importance in the selection of an appropriate model for a particular application is the need for the hydrological problem to be clearly defined. In general, the simplest model which will provide acceptable accuracy should be adopted. A good database is a crucial requirement to support modelling; if the field data are of limited accuracy, model predictions will also be of limited accuracy, regardless of the model adopted. While computer capabilities have been greatly enhanced in recent years, data quality has increasingly become a major limitation. It is in this context that the potential of remote sensing for integrating information over entire watersheds offers great advances.

42. Models for flood forecasting can be improved by using geographic information from topographic, geological and soil maps and other information on vegetation and land use distribution. The models can also incorporate satellite data directly, including continuously updated data on hydrological conditions in the watershed. In addition to being used for flood prediction, the models can be used to study the hypothetical effect of land-use change, deforestation, etc., on run-off and flooding.

43. Despite the uncertainties in the prediction of water levels and flow in a watershed due to the variability of rainfall, snow-melt, run-off and river flow in space and time, even a basic two-dimensional flow prediction, based on the laws of conservation of mass, momentum and energy via the equations of continuity, can provide useful results. Considering that percolation and evaporation play an insignificant role during a flood situation, a simple empirical relationship can be used to relate the volume of flow and the cross-sectional area of the river as they vary in time and in position along the length of the river.

44. Flood routing refers to mathematical models that predict the changing magnitude, speed and shape of a flood wave as it propagates along waterways. The flood wave can begin with precipitation run-off, a breach in a reservoir or other cause. In general, flood damage can be predicted by applying the run-off model for the basin, using the equations of wave propagation to predict flood wave movement in the downstream areas, and then predicting where the high water levels would cause damage. More simply, the severity of flood damage could also be assessed using the predicted extremes in the run-off characteristics, including: (a) the total and peak rainfall over the watershed area; (b) the time difference between the maximum rainfall and the peak of the run-off; and (c) the rise and fall of the run-off.

45. One simplified river flow model calculates the peak flow using the rainfall intensity, the rate of water loss due to infiltration and evaporation, the duration of rainfall, the rate of snow-melt run-off and the contributing watershed area. The mathematical model includes a coefficient, determined for each watershed, that relates the observed parameters to the predicted peak flow. As a simplification, the model neglects lateral inflow, frictional resistance and non-linear terms, but it still provides useful predictions in many cases.

46. Since it is very difficult to develop a general hydrological model that is applicable to all watersheds, a variety of models have been developed for specific conditions. In general, kinematic wave models are useful for predicting flood waves on steep streams where the water level increases rapidly following heavy rainfall. Diffusive wave models are generally more applicable to rivers with gentler slopes. In the case of a flood wave of large magnitude on a wide river, dynamic wave models are usually best. When the flow rate upstream is known over time and space, wave propagation models can be used to estimate the movement of the flood wave downstream. The selection of a model in a particular case will depend on the nature of the river basin and the data that are available.

III. SPACE TECHNOLOGY AND FLOOD MANAGEMENT

A. Satellite and ground data

47. The unique capabilities of satellites to provide comprehensive coverage of very large areas at regular intervals and with quick availability have been very valuable in monitoring, controlling and managing floods. In fact, it is only through space technology that basic information has become available for the first time in many areas.

48. Space imagery and digital data can provide valuable information for carrying out flood management measures, including measures for moderating flood waves, for modifying susceptibility of flood plains to flooding and for modifying the impact of flooding. In order for appropriate flood-control and erosion-control measures to be planned, executed, monitored and maintained according to the best standards, it is necessary to acquire timely and reliable information about weather conditions, river behaviour, flooded areas and other factors, at intervals prior to floods, during floods and after floods.

49. Such information is difficult to acquire in time for decision-making by conventional ground survey methods, which can be time-consuming and expensive as well as physically difficult, and which pose a variety of practical problems and even dangers, especially in the case of large river basins. It is largely because of these difficulties with conventional surveying that the use of space technologies offers such great benefits. Despite the limitations due to cloud cover and the rather long periods between remote sensing satellite overflights, satellites, by virtue of their automatic repetitive coverage and instantaneous data transmission capabilities, are able to provide comprehensive multi-date and multi-spectral information on dynamic phenomena covering very large as well as small river basins. In particular, satellites have been found to be admirably

suited for mapping, monitoring and studying the following parameters: (a) flooded and poorly drained areas; (b) extent of damage to crops, structures, etc.; (c) river configuration, silt deposits, shoals, etc.; and (d) watershed characteristics, land cover and land use in river basins.

50. The use of meteorological satellites, including the United States National Oceanic and Atmospheric Administration (NOAA) and Geostationary Operational Environmental Satellite (GOES), the Soviet METEOR satellites of the Union of Soviet Socialist Republics, the European Meteosat, the Japanese Geostationary Meteorological Satellite (GMS) and the Indian National Satellite System for Television and Telecommunications (INSAT), for forecasting heavy rainfall and snow-melt run-off, and for monitoring convective and frontal weather systems, has greatly improved observational systems. The use of high-resolution remote sensing data from SPOT, Landsat, Soviet remote sensing satellites and the Indian Remote Sensing Satellite (IRS) has greatly contributed to our understanding of various parameters, including drainage area, land use, soil type and topography, that affect rainfall run-off analysis and flood forecasting.

51. The data from IRS, as well as Landsat, SPOT and NOAA, are used on a routine basis in India to obtain near real-time information on damage due to floods. Flood maps showing areas of standing water, wet areas and crop damage are produced within a week and distributed to district authorities responsible for providing relief. Identification and mapping of flood-prone areas is also used for land use planning.

52. Flooded areas, which may extend over several thousand square kilometres, can be very effectively mapped using satellite data. The data are also useful in delineating the boundaries of flood-prone zones. The repetitive historical data from satellites have proved to be very valuable in the identification of sites for flood control structures. For river deltas extending over large areas, satellite data are eminently suited for studies of sediment deposits, flood-regulating capacities, river-course variations and studies of estuaries. Since the timely availability of maps of flooded areas becomes a crucial factor both for taking appropriate remedial measures to mitigate the sufferings of affected people and for making reliable estimates of damage, satellite data are often indispensable.

53. Type, amount and distribution of precipitation are crucial parameters in flood forecasting, and satellites are most useful for monitoring them. Conventional rain gauge estimates provide continuous quantitative data through time, but represent rainfall only at a single location. Satellite data provide complete geographical coverage, but only at discrete intervals or points in time. A combination of the two types of data can therefore give a total picture of the rainfall characteristics of the area. Satellites also have the capability to collect, transmit and disseminate data from automatic sensors located at strategic points around a watershed. The sensors are placed on data collection platforms (DCPs) which collect and transmit data to a central receiving station.

54. The frequency of flooding as a function of the flooded area can be estimated by observing a number of flood events by remote sensing satellites. Satellite maps can provide permanent records of past flooding, providing important historical data for such statistical analysis. Those flood risk estimates can be used to great

advantage in the planning of new developments. Flood plains can be delineated using meteorological, physiographic, geomorphic, topographic, pedological and socio-economic data that can be deduced from remotely sensed data through multispectral analysis and spatial variation patterns. Another approach uses computer-analysed remote sensing data combined with digital elevation data to estimate the relationship between river flow and inundation area. There have been a few case studies in which the effect of changes in land use on run-off was studied. There is a great need for further studies in which satellite and ground-based data are integrated to secure greater protection from floods.

B. Satellites with flood applications

55. The Landsat series of remote sensing satellites provides multi-spectral capabilities and resolution sufficient for flood applications even on smaller basins, but the frequency of coverage is inadequate for routine operational purposes. With two Landsat satellites in orbit, a given area is surveyed twice every 18 days. Because of cloud cover, it is entirely possible that no useful data will be collected by Landsat in a given flood period.

56. Landsat satellites carry a Multi-Spectral Scanner (MSS) and a Thematic Mapper (TM). The MSS records four spectral images of a scene covering a ground area of 185 km by 185 km, with a ground resolution of 80 m. The four images represent the scene in green, red and near infrared spectral bands. The TM carried by Landsats 4 and 5 records images in six spectral bands with a spatial resolution of about 30 m, with a thermal infrared band with a spatial resolution of 120 m. (The Landsat Thematic Mapper spectral bands and their applications are listed in appendix III.)

57. The extent of flooding can be dramatically shown by combining satellite images acquired during normal conditions and during the flood. When a normal image is projected as red, superimposed on a flood image projected as green, the composite colour image is composed of the following elements:

(a) Where there is surface water present in both images, the composite image is black, depicting the area normally covered by the river and other surface water bodies;

(b) Where the ground is not covered with water in both images, the composite image is yellow, depicting the area unaffected by flood waters;

(c) Where there is surface water in the flood image and dry ground in the normal image, the composite image is a highly saturated red colour, depicting the flooded area;

(d) Where there is water-saturated soil in the flood image and dry ground in the normal image, the composite image is a colour between yellow and red, depending on the wetness of the ground.

58. The NOAA satellites are more limited in spatial resolution and multi-spectral capability. While meteorological satellite observations of floods are also limited by cloud cover, the twice-daily visible and infrared coverage greatly increases the probability of acquiring images that will allow the monitoring of floods and factors that affect flooding as the situation develops over large areas.

59. The GOES geostationary satellites, which acquire data every half-hour, are particularly well suited to monitoring rapidly changing variables such as convective storms crossing a basin during a flood. However, the GOES spatial resolution and the geometric distortion towards the edges of the image make it difficult to register the image on a reference map.

60. The Meteosat geostationary satellite of the European Space Agency (ESA) carries a multi-spectral radiometer with a visible channel, a thermal infrared channel in the 10.5-12.5 μm band, and an infrared water vapour channel in the 3.7-7.1 μm spectral band. The spatial resolution at the sub-satellite point is approximately 2.5 km in the visible band and 5 km in the thermal infrared and water vapour bands.

C. Recent satellite flood studies

61. Surveys of the practical applications of satellite remote sensing to water resources, including floods and snow cover, with extensive bibliographies, have been provided recently by Chow et al. (1988), Reed (1984) and Rao (1990). A survey paper on the applications of weather radar systems in meteorology and hydrology has been published by Collier (1989). These papers also discuss flood mapping, snow-cover determination, river-ice breakup monitoring and precipitation estimates.

62. Satellite observations of the 1973 Mississippi River flood have been extensively described by a number of authors in a report of the American Water Resources Association (1974). That study stands as an example of the analysis of Landsat imagery for detecting a number of flood plain features, including levee systems, soil types, upland boundaries, agricultural patterns, channel configurations and possible backwater areas.

63. Ramamoorthi (1989) has reported on the application of satellite imagery to flood mapping in India. In 1988 in particular, floods were mapped in real time and estimates were made of crop damages due to floods in the Ganga and Brahmaputra basins. SPOT and NOAA images have also been used for this purpose. Both visual and digital analysis have been used in detailed investigations of a variety of features: (a) flood-affected area mapping; (b) flooding due to breach of embankments; (c) drainage-congested area mapping; (d) flood damage assessment and relief; (e) river bank erosion; (f) flood-risk zone mapping; and (g) flood forecasting.

64. A study by Gallolti Florenzano (1989) of sections of the Amazon river valley, the Paraná and Doce river valleys and other areas in the north-east of Brazil illustrates the application of satellite imagery for identifying and mapping flooded areas. Digital and analog Landsat data of both normal and flood conditions

were used to prepare detailed flood maps of the areas. A study to evaluate Landsat data for surveying fluvial geomorphology features and their relationship to flood conditions was also carried out in the Doce river valley. Multi-temporal Landsat data covering three river flow conditions were used to classify the upper Paraná river according to hazard levels of flooding events.

65. Balogun (1989) has described the use of Meteosat imagery for the study of flood-producing weather patterns over the West African region. The most important weather patterns are the convective systems which develop over the region on various space and time scales. The visible and infrared sensors on Meteosat provide cloud cover data over the West African region on an almost continuous day-and-night basis. Balogun discusses configurations of cloud patterns that often produce heavy rainfall and demonstrates the application and the promise of Meteosat imagery in the monitoring of flood-producing weather over West Africa.

IV. FUTURE PROSPECTS

66. Existing remote sensing and meteorological satellites carry sensors that make observations in the visible and infrared spectral bands which are relatively easy to interpret but totally dependent on weather conditions, since such signals can be wholly obscured by clouds. The visible and near infrared sensors are also limited to daylight observations. This major limitation on the use of remote sensing for flood mapping and monitoring can be overcome through the use of sensors that make observations in the microwave region of the electromagnetic spectrum. In particular, imaging radar systems offer all-weather, day-and-night imaging capabilities. The disadvantages of radar systems are that they are complex and expensive, with respect to both the satellite and the ground reception and processing, and the images can be difficult to interpret. In some tropical areas, persistent cloud cover has made it very difficult to acquire good conventional remote sensing images, and radar offers a reliable means of mapping in such areas.

67. The development of radar applications has been limited primarily by lack of data. The short-lived Seasat mission in 1978 and the brief Shuttle Imaging Radar (SIR) missions have produced data that are very interesting, but very limited in time and coverage. None the less, they have effectively demonstrated the capabilities of radar for flood mapping.

68. While detailed interpretation of radar images can be difficult, the distinction between land and water is usually very clear since water surfaces appear as uniform black while land surfaces appear as various shades of grey. This characteristic, along with the ability to see through cloud cover, makes satellite radar ideal for monitoring flooded areas. Repetitive observations allow studies of flood dynamics. Radar images are particularly effective in revealing topography and hence are useful for mapping drainage networks in mountainous areas, a characteristic that can be useful in planning water conservation measures in the upper parts of watersheds. Other features can be more difficult to interpret, but radar images can distinguish flood plains from valley slopes, cleared land from forested land and settled areas from open land. While conventional remote sensing images, where available, are probably generally preferable for flood plain mapping, radar images are a useful alternative or complementary source of information.

Because water appears as uniform black on radar images, they provide no information on sedimentation patterns.

69. The lack of satellite radar images will be remedied in the near future. The USSR has recently launched the first of the Almaz series of remote sensing satellites with radar sensors, and radar sensors are to be included on the ESA European Remote Sensing (ERS-1) satellite to be launched in 1991, the Japanese Earth Resources Satellite (JERS) to be launched in 1992 and the Canadian Radarsat planned for 1994. In general, the availability of these data will depend upon the ability of local ground receiving stations to receive and process the data.

70. Remote sensing satellites send a vast quantity of data back to the ground, and future satellites will increase this amount substantially. The limited skills and resources for processing and interpreting these data is a major limitation on their effective use. In the future, developments in computers, in computer software and particularly in the use of artificial intelligence is expected to help in handling the enormous flows of data and information and transforming them into useful knowledge.

71. The remote sensing and meteorological satellites now under development or planned will increase both the number and the variety of sources of data for flood management. These systems will be used most effectively if they are co-ordinated so as to provide complementary data. The phasing of satellite orbits in order to maximize the frequency of repetitive coverage, the compatibility of data formats so as to minimize the costs of data reception and processing as well as the continuity of types of data are important factors in promoting the wide use of satellite data. Increased international and regional co-operation in building and launching satellites and in building and operating ground receiving and processing facilities can help to make satellite data available at reasonable cost.

72. Aerial and ground surveys will continue to be needed to collect data that cannot be collected by satellite and to support the interpretation of satellite images. None the less, the lower costs of satellite surveys, particularly for large areas, will mean that satellite applications will continue to replace some aerial and ground surveys.

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Appendix I

MAJOR FLOODS WITHIN THE PAST CENTURY

Year	Location and cause
1883	Java and Sumatra. Tsunami, following the explosion of Krakatoa. Some 36,000 lives lost.
1887	China. Huang He River, swollen by rains, overflows levees, floods 150,000 km^2 (50,000 sq. mi.). 900,000 lives lost.
1889	Johnstown (Pennsylania, United States). Dam failure. 2,200 lives lost.
1900	Galveston (Texas). Hurricane flooding. 6,000 lives lost.
1916	The Netherlands. North Sea storms flood lowlands. 10,000 lives lost.
1928	Florida. Hurricane causes Lake Okeechobee to flood. 2,400 lives lost.
1938	North China. Chinese forces blow up dikes on Huang He River, to impede Japanese advance. Estimated 1 million lives lost.
1960	Chile, Hawaii, Japan. Giant tsunami following a major Chilean earthquake inundates coastal areas in all three countries.
1963	Northern Italy. Landslide into the reservoir of the Vaiont Dam sends a huge wave into valley below. 2,000 lives lost.
1970	East Pakistan (now Bangladesh). Cyclone-generated floods inundate coastal regions. 200,000 lives lost.
1971	Orissa State, India. Cyclone and sea surge hit the coast. 10,000 lives lost.
1979	Morvi, India. Heavy monsoon rains cause collapse of river dam. 7,000 to 10,000 lives lost.
1982	Peru. Torrential rains cause lake to overflow into Chantayacu River Valley. 2,500 lives lost.
1985	North-eastern Brazil. Rain-caused floods leave 1 million homeless.
1988	Bangladesh. Monsoon flooding inundates three quarters of country. 28 million homeless.
1988	Sudan. Torrential rains flood the Nile. 1.5 million homeless in Khartoum areas; number of dead unknown.

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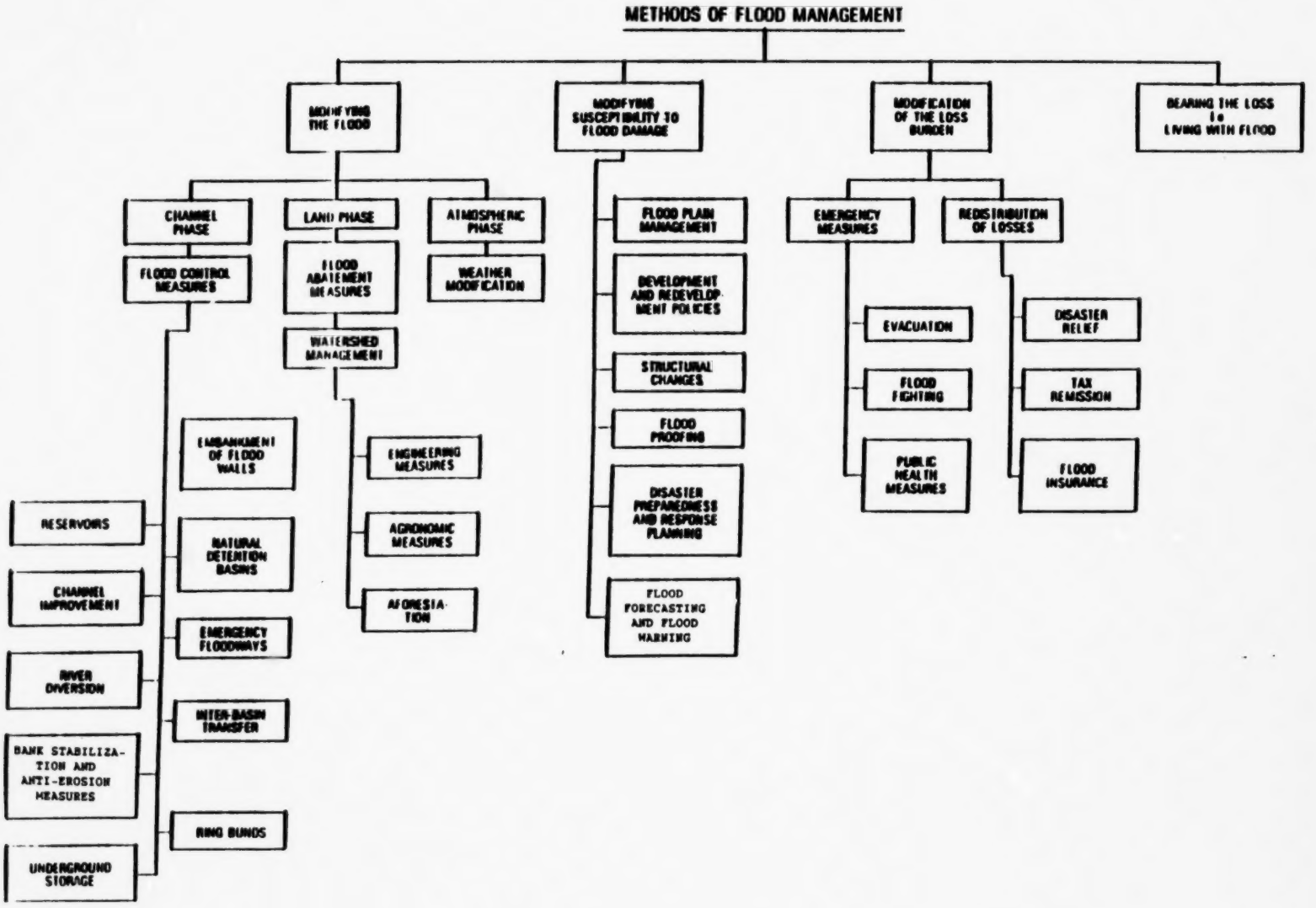
Appendix II


METHODS OF FLOOD MANAGEMENT
MODIFYING THE FLOOD
MODIFYING SUSCEPTIBILITY TO FLOOD DAMAGE
MODIFICATION OF THE LOSS BURDEN
BEARING THE LOSS i.e LIVING WITH FLOOD
CHANNEL PHASE
LAND PHASE
ATMOSPHERIC PHASE
FLOOD CONTROL MEASURES
FLOOD ABATEMENT MEASURES
WEATHER MODIFICATION
WATERSHED MANAGEMENT
EMBANKMENT OF FLOOD WALLS
ENGINEERING MEASURES
RESERVOIRS
NATURAL DETENTION BASINS
AGRONOMIC MEASURES
CHANNEL IMPROVEMENT
EMERGENCY FLOODWAYS
AFORESIATION
RIVER DIVERSION
INTER-BASIN TRANSFER
BANK STABILIZATION AND ANTI-EROSION MEASURES
RING BUNDS
UNDERGROUND STORAGE
FLOOD PLAIN MANAGEMENT
DEVELOPMENT AND REDEVELOPMENT POLICIES
STRUCTURAL CHANGES
FLOOD PROOFING
DISASTER PREPAREDNESS AND RESPONSE PLANNING
FLOOD FORECASTING AND FLOOD WARNING
EMERGENCY MEASURES
REDISTRIBUTION OF LOSSES
EVACUATION
DISASTER RELIEF
FLOOD FIGHTING
TAX REMISSION
PUBLIC HEALTH MEASURES
FLOOD INSURANCE

Appendix III

LANDSAT THEMATIC MAPPER SPECTRAL BANDS AND APPLICATIONS

Band	Colour	Wavelength (μm)	Applications
1	Blue/green	0.45-0.52	Good water penetration, strong vegetation absorption
2	Green	0.52-0.60	Strong vegetation reflectance
3	Red	0.63-0.69	Very strong vegetation absorption
4	Near infrared	0.76-0.90	High land/water contrast, very strong vegetation reflectance
5	Near-middle infrared	1.55-1.75	Very sensitive to moisture
6	Thermal infrared	10.4-12.5	Very sensitive to soil moisture and vegetation
7	Middle infrared	2.08-2.35	Good geological discrimination

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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

CO-OPERATIVE ARRANGEMENTS IN SUPPORT OF THE IMPLEMENTATION OF THE UNITED NATIONS PROGRAMME ON SPACE APPLICATIONS*

Report of the Secretariat in response to the request of the Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space

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* The present report deals only with the financial arrangements within the United Nations system in support of the United Nations Programme on Space Applications. The full co-operative arrangements of the United Nations system regarding outer space activities can be found in the report entitled "Co-ordination of outer space activities within the United Nations system: programme of work for 1991 and 1992 and future years" (A/AC.105/465).

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INTRODUCTION

1. The Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), in the report on the work of its fourth session, made a series of recommendations concerning the preparation of reports and studies by the Secretariat and the compilation of information from Member States (A/AC.105/456, annex II, paras. 4-6).

2. Noting that many of the recommendations contained in the report of UNISPACE 82 (A/CONF.101/10 and Corr.1 and 2) had still not been fully implemented, the Working Group, in paragraph 4 (f) of its report, recommended that in formulating co-operative programmes and projects intensive participation of international and regional financial and development institutions should be encouraged by the United Nations. In this connection, the Working Group requested the Secretariat to report annually on the arrangements it has made with other organs, bodies and organizations of the United Nations system in order to utilize fully the available resources and to secure additional financial support from other sources for the continued implementation of the United Nations Programme on Space Applications. The present report was prepared by the Outer Space Affairs Division in response to the above request.

3. For the activities undertaken by the Outer Space Affairs Division, and in particular those of the United Nations Programme on Space Applications, the specialized agencies of the United Nations are invited to co-sponsor the activities that fall within their respective areas of competence. Similar invitations are made to the regional economic commissions of the regions in which the activities are held, as well as to other concerned bodies of the United Nations. The co-sponsoring organizations share the costs of the activities. The specific arrangements regarding such co-sponsorship are agreed upon during the annual inter-agency meetings on outer space activities that serve to co-ordinate the efforts of the United Nations system, as well as during the annual sessions of the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Sub-Committee.

I. SHORT-TERM TRAINING ACTIVITIES OF THE UNITED NATIONS PROGRAMME ON SPACE APPLICATIONS

4. Activities such as workshops, courses, seminars and meetings of experts organized by the Programme on Space Applications are sponsored by the United Nations, by other entities of the United Nations system and by the host Government of the country in which the activity is held. Other governmental, intergovernmental and non-governmental organizations co-sponsor many of these activities of the Programme. In a manner similar to the co-operation arrangements with other entities of the United Nations system, the Programme discusses co-sponsorship arrangements for specific activities with organizations outside the system with a two-year lead time.

5. The Programme discusses the activities proposed for a given year with all potential co-sponsors, who decide whether to participate on the basis of their own programmes, priorities and resources. In some cases, arrangements have been made that have led to the establishment of a continuing series of activities on specific topics on a yearly or bi-yearly basis and co-sponsored by the same organizations. Within an established series, some of the activities have also been co-sponsored by other specialized agencies and Governments for topics of special interest to them. A complete list of the workshops, courses, meetings of experts and seminars organized by the Programme since UNISPACE 82 together with their respective co-sponsors and host Governments is given in annex I to the present report. The established series of activities include the following:

(a) United Nations/Food and Agriculture Organization of the United Nations (FAO) International Training Course on Remote Sensing Applications, co-sponsored by the Government of Italy; 14 courses have been held in this series;

(b) United Nations/FAO/European Space Agency (ESA) Workshop on Microwave Remote Sensing Techology; two workshops have been held in this series;

(c) United Nations/FAO/World Meteorological Organization (WMO)/ESA Training Course on Remote Sensing and Satellite Meteorology Applications to Agrometeorology and Hydrology; five courses have been held in this series;

(d) United Nations International Training Course on Remote Sensing Applications/Seminar on Space Communications, co-sponsored by the Government of the Union of Soviet Socialist Republics; six activities have been held in this series;

(e) United Nations/Committee on Space Research (COSPAR) Workshop on Space Research, held during the COSPAR plenary meeting (bi-yearly); seven workshops have been held in this series;

(f) United Nations/International Astronautical Federation (IAF) Workshop on Space Applications, held during the current-events session of the IAF Congress; three workshops have been held in this series;

(g) Latin American Society of Remote Sensing Specialists (SELPER) Latin American Symposium on Remote Sensing; four symposia have been co-sponsored in this series.

6. The Programme on Space Applications also sponsors and contributes to the technical content of short-term activities that are initiated by other bodies of the United Nations system. In particular, in 1990 the Programme co-sponsored with FAO, the International Training Course on Agriculture Applications of Remote Sensing, held in Prague from 18 to 29 June. Likewise, the Programme co-sponsored the United Nations/FAO/ESA International Workshop on Remote Sensing: Geo-Information Technology for Decision Makers, held in Rome from 7 to 16 November in co-operation with the Government of France.

7. The costs of organizing the short-term activities of the Programme vary considerably depending upon the duration of each activity, the number of

participants that are financially supported (travel and per diem) and the local cost of living. The total expenditure for each activity is covered from a combination of sources including the Programme's regular budget and Trust Fund (voluntary contributions of Member States) as well as financial and in-kind contributions from the host Government/institution, bodies of the United Nations system and other Governments and international organizations. Annex II shows the ranges of estimated costs for the various categories of expenditure associated with the organization of short-term activities. Due to budgetary limitations, the expenses incurred by the Programme for any one activity do not exceed $US 35,000, with the balance coming from other co-sponsors. Thus, the regular budget and Trust Fund of the Programme provide only "seed funding" for the short-term activities.

II. LONG-TERM AND INDIGENOUS CAPABILITY-BUILDING ACTIVITIES OF THE UNITED NATIONS PROGRAMME ON SPACE APPLICATIONS

Long-term education

8. As indicated in the report entitled "United Nations activities relating to space applications" (A/AC.105/454), in 1989 the Programme on Space Applications administered 40 long-term fellowships for in-depth training in basic space sciences, remote sensing, satellite communications and satellite meteorology. During 1990, three of those fellowships (basic space sciences, satellite geodesy and remote sensing) were discontinued as a result of the unification of Germany. During the same period, the Programme administered two new long-term fellowships on geodesy, photogrammetry and remote sensing offered by the Government of China and five additional fellowships on remote sensing instrumentation and ecological monitoring offered by the Soviet Union. Thus there was a total of 44 long-term fellowships administered by the Programme in 1990.

9. The Programme is currently seeking the financial support of the United Nations Development Programme (UNDP) for the establishment of regional centres for space science and technology education in developing countries (A/AC.105/478, paras. 35-44). For this purpose, the Outer Space Affairs Division has prepared a project proposal document which has been distributed to all developing countries through their corresponding regional economic commissions so that they may indicate their interest in hosting and/or supporting the centres. Discussions are also in progress with several of the specialized agencies and other bodies of the United Nations system with a view to maximizing their contribution to the establishment of the centres. Additional technical and financial support will be solicited from other Member States as well as from regional and international institutions.

Indigenous capability building

10. The Programme on Space Applications also seeks the co-operation of other bodies of the United Nations system in supporting activities that strengthen the indigenous capability of developing countries in areas of space science and technology. In particular, in 1990 the Programme assisted in the organization of the Space Conference of the Americas held at San José, Costa Rica, from 12 to 16 March, which included the participation of the United Nations system. The

Conference was financed in part by the UNDP and the United Nations Fund for Science and Technology for Development (A/AC.105/478, paras. 12 and 13). The Programme also assisted the Economic Commission for Africa (ECA) in conducting a fact-finding mission to assess the administrative and technical capabilities of the Regional Centre for Services in Surveying, Mapping and Remote Sensing to adequately meet the needs of its Member States (A/AC.105/478, para. 16). The fact-finding mission was financed by ECA.

11. Two meetings of experts on remote sensing applications organized by the Programme and financially supported by UNDP in 1989 have resulted in remote sensing activities that are being implemented in the Africa and Indian Ocean regions in the period 1990-1992. The meeting of experts held at Maspalomas, Spain (A/AC.105/436) has led to a joint United Nations/ESA activity whereby ESA will provide satellite data sets over selected sites in Africa that are within the coverage of the Fucino and Maspalomas ground receiving stations. This activity, which includes a training element, is being financed by ESA. The meeting of experts held at Karachi, Pakistan (A/AC.105/439) has led to three pilot projects on remote sensing applications that are being carried out in the Indian Ocean region. These pilot projects are being supported by the Government of France and UNDP.

III. CONCLUSIONS

12. The Programme on Space Applications continuously seeks material and financial support from other entities of the United Nations system as well as from governmental and international organizations regarding the implementation of the elements of its mandate. Some Governments, specialized agencies of the United Nations (FAO, WMO) and international organizations, particularly the European Space Agency, have provided financial support for the activities of the Programme on a continuous basis since UNISPACE 82. However, the Programme's regular budget and Trust Fund are the only financial sources directly available to it to enable it to carry out all its activities. Short-term activities are financed from both of these sources, and although the activities are successfully carried out through funding arrangements negotiated on an ad hoc basis for each activity the Programme lacks flexibility in planning and carrying out the activities. The Trust Fund is the only source of financing available to implement the expanded activities recommended by UNISPACE 82. The low (and steadily decreasing) level of the Trust Fund, if not redressed, will continue to limit the ability of the Programme to implement the UNISPACE recommendations.

Annex I

WORKSHOPS, COURSES, SEMINARS AND MEETINGS OF EXPERTS CONDUCTED BY THE UNITED NATIONS PROGRAMME ON SPACE APPLICATIONS FOLLOWING UNISPACE 82

Title	Sponsor(s)	Co-sponsor(s) and host	Year
Regional seminar on space applications focusing on the implementation of the recommendations of UNISPACE 82 (ECLAC)	United Nations	Brazil	1983
Regional seminar on space applications focusing on the implementation of the recommendations of UNISPACE 82 (ESCAP)	United Nations/ESCAP	Thailand	
Regional seminar on space applications focusing on the implementation of the recommendations of UNISPACE 82 (ECA, ESCWA)	United Nations/ECA	Ethiopia	
First international training course on remote sensing applications to operational agrometeorology in semi-arid countries	United Nations/WMO/ ESA/FAO	Niger	
Eighth international training course on the applications of satellite remote sensing focusing on water resources	United Nations/FAO/ UNESCO	Italy	
International Meeting of Experts on Remote Sensing Information Systems	United Nations	Federal Republic of Germany	1984
Ninth international training course, focusing on the applications of remote sensing to aquaculture and inland fisheries	United Nations/FAO	Italy	

Title	Sponsor(s)	Co-sponsor(s) and host	Year
Third international training course on remote sensing applications to forestry	United Nations/UNEP	USSR	
Meeting of experts on regional co-operation on space science and technology and its applications	United Nations/ESCAP	Indonesia	
Second international training course on remote sensing applications to operational agrometeorology and hydrology	United Nations/WMO/ FAO/ESA	Kenya/Sweden	1985
Workshop on remote sensing instrumentation, data acquisition and analysis	United Nations	Bulgaria	
International training course on remote sensing applications to monitoring forest lands	United Nations/FAO	Italy/Federal Republic of Germany	
International seminar on satellite communications	United Nations	USSR	
Workshop on advances in space science and technology and its applications	United Nations	China	
Workshop on space science and technology and its applications within the framework of educational systems	United Nations	India	
Eleventh international training course on remote sensing applications in agricultural statistics	United Nations/FAO	Italy/France	1986
Meeting of experts on regional co-operation in space science and technology and its applications	United Nations/ECLAC	Colombia	

Title	Sponsor(s)	Co-sponsor(s) and host	Year
Regional meeting of experts on space technology applications in the Indian Ocean region	United Nations	Sri Lanka	
Training course on drought assessment and vegetation monitoring using meteorological satellite and other space-related data	United Nations/ESA/FAO	France/Spain	
Meeting of experts on space science and technology and its applications within the framework of educational systems	United Nations	Mexico	
Third international training course on remote sensing applications to operational agrometeorology and hydrology	United Nations/WMO/FAO/ESA	Ecuador	
Interregional meeting of experts on space science and technology and its applications within the framework of educational systems	United Nations	Nigeria	1987
Twelfth international training course on the applications of remote sensing to marine fisheries	United Nations/FAO	Italy	1987
International seminar on space communications	United Nations	USSR	
Training course on remote sensing applications to geological sciences	United Nations	German Democratic Republic	

Title	Sponsor(s)	Co-sponsor(s) and host	Year
Fourth international training course on the applications of remote sensing to operational agrometeorology and hydrology	United Nations/WMO/FAO/ESA	Indonesia	
Training course on applications of remote sensing and agrometeorological data to drought assessment and vegetation	United Nations/FAO/WMO/ESA	Kenya/France	1988
International seminar on the development and applications of satellite communication systems	United Nations	China	
Workshop on microwave remote sensing technology	United Nations/ESA	Thailand	
Thirteenth international training course on the applications of remote sensing to water resources	United Nations	Italy	
Workshop on regional space information systems	United Nations	Peru	
Meeting of experts on remote sensing and satellite meteorology applications to marine resources and coastal management	United Nations/UNDP/FAO/ESA	Spain	1989
Fifth international training course on the use of remote sensing systems in hydrological and agrometeorological applications	United Nations/FAO/WMO/ESA/ESCAP	Australia	

Title	Sponsor(s)	Co-sponsor(s) and host	Year
International meeting of experts on the development of remote sensing skills and knowledge	United Nations	United Kingdom	
Workshop on oceanographic/ marine space information systems	United Nations/IOMAC/ UNESCO	Pakistan	
Training course on the use of remote sensing data in agriculture management	United Nations	USSR	
Second training course on remote sensing applications to geological sciences	United Nations	German Democratic Republic	
Fourteenth international training course on remote sensing applications to land resources	United Nations/FAO	Italy	
United Nations Workshop on Space Communications for Development	United Nations	Cuba	1990
United Nations/FAO/ESA International Remote Sensing Workshop: Geo-information Technology for Decision Makers	United Nations/FAO/ESA	France	
United Nations Training Course on Remote Sensing for Educators	United Nations	Sweden	
United Nations/FAO/ESA Workshop on Microwave Remote Sensing Technology	United Nations/FAO/ESA	Brazil	

Annex II

RANGES OF COSTS ASSOCIATED WITH THE ORGANIZATION OF SHORT-TERM TRAINING ACTIVITIES

(In thousands of United States dollars)

Length of activity: 1-3 weeks; 20-25 financed participants

Category	Sources of financing	
	United Nations	Host Government/ sponsoring agency
1. Participants		
Foreign		
Room and Board	3.0 - 12.0	10.0 - 130.0
International travel	12.0 - 25.0	10.0 - 25.0
Local		
Board	1.0 - 1.5	1.0 - 2.0
2. United Nations staff		
Per diem	1.0 - 3.5	-
International travel	1.0 - 2.5	-
3. Lecturers/instructors		
Per diem	1.0 - 1.5	2.0 - 10.0
International travel	1.0 - 2.0	2.0 - 20.0
4. Facilities, equipment, educational materials		
Local support	-	20.0 - 50.0
5. Local transportation	-	3.0 - 25.0 a/
	20.0 - 48.0 b/	48.0 - 262.0 c/

a/ Upper limit includes air transportation within host country.

b/ Due to budgetary limitations, overall costs for the Programme do not exceed $35,000 for one activity.

c/ The limits of the range depend upon (i) course duration; (ii) number of participants; and (iii) whether the course is held in a high- or low-cost-of-living city.